OCTOBER, 1959

Welding Journal

See Page 969

IN THIS ISSUE

Principles of Modern Arc Torch 959
Fusion Welding Precipitation-hardening Steels 963
Ultrasonic Welding of Aluminum 969
Dip-transfer Carbon-dioxide Welding 976
Extrusions in Tank Fabrication 982
New System for Automatic Feedback Control 987
Welding of Nickel-molybdenum Alloys 393-s
Electron-beam Welding 401-s
Welding of Beryllium 410-s
Static Brittle-fracture Initiation 414-s
Index to Advertisers 1046

FICIAL PUBLICATION OF THE AMERICAN WELDING SOCIETY

Preheating carbon-moly tubing with Victor Model J27 torch and Type 28 heating nozzle at Besler Corp., Emeryville, Calif.

The man on the job likes Victor torch flexibility

Flexibility is built into all Victor torches, regardless of size. Here, for example, Series J torches are being used to preheat, then weld ⅝" O.D. with .095" wall tubing for steam generators. With a change of nozzles and tips these same torches braze and solder . . . with the addition of a cutting attachment, can be used for light cutting applications and occasional short jobs up to approximately 2" steel.

Victor Series 100 torches for medium-duty work and the famous Series 300 for tough, heavy work, give you this same flexibility . . . heating, welding, brazing, soldering, cutting. All 3 sizes, with proper cutting attachment, can be used with oxygen-acetylene, oxygen-propane, oxygen-city or natural gas.

Ask your Victor dealer for a demonstration now. You'll see for yourself how Victor torches answer all your welding and cutting needs.

Welding ⅝" O.D. with .095" wall tube into generator coil, using Model J27 torch and Type 17 welding nozzle with oxy-acetylene.

Profitable dealerships open in a few areas; inquire now.

VICTOR for welding and cutting

VICTOR EQUIPMENT COMPANY

Mfrs. of welding & cutting equipment; high pressure and large volume gas regulators; hardfacing rods, blasting nozzles; cobalt & tungsten castings; straightline and shape cutting machines.

62

844 Folsom St., San Francisco 7 • 3821 Santa Fe Avenue, Los Angeles 58
1145 E. 76th St., Chicago 19
J. C. Menzies & Co., Wholly-Owned Subsidiary
For details, circle No. 1 on Reader Information Card

VOLUME 38 • NUMBER 10 • OCTOBER 1959

Welding Journal

Technical Papers Items and Reports

The Principles of the Modern Arc Torch, by R. M. Gage 959
Fusion Welding Precipitation-hardening Steels, by Russell Meredith 963
Ultrasonic Welding of Aluminum, by F. R. Collins, J. D. Dowd and M. W. Brennecke 969
Dip-transfer Carbon-dioxide Welding, by Roger W. Tuthill 976
Extrusions in Tank Fabrication, by Martin J. Coen 982
A New System for Automatic Feedback Control, by G. R. Archer 987

Practical Welder and Designer

Gas-Shielded Metal-arc Welding Used in Fabricating Intricate Processing Controls, by Glenn Hartwick and Glenn Warren 994
Cool Air and Ice...Thanks to a 6000° Flame 996
Spray Hard Surfacing Increases Service Life of Fans 20 Times, by J. E. Looney and S. L. Newcom 998

Society and Related Events

Press-Time News 948
Welding Zones 950
World-Wide Welding News 952
Editorial—Welding—A Basic Industry, by W. Harnischfeger 957
Society News 1002
Section News and Events 1016
New Members 1018
Abstracts of Current Patents 1019
Current Welding Literature 1020
News of the Industry 1021
Personnel 1028
Employment Service Bulletin 1029
New Literature 1030
New Products 1037
Index to Advertisers 1046

Welding Research Supplement

Welding of Nickel-Molybdenum Alloys, by G. M. Slaughter, P. Patriarca and R. E. Clausing 393-s
Electron-beam Welding, by G. Burton, Jr. and W. L. Frankhouser 401-s
Welding of Beryllium, by E. L. Brundige, R. S. Kirby, G. S. Hanks and J. M. Taub 410-s
Prestrain, Size and Residual Stresses in Static Brittle-fracture Initiation, by C. Mylonas 414-s

Published for the advancement of the science and art of welding by the American Welding Society

Published monthly by the American Welding Society. Publication office, 20th and Northampton Streets, Easton, Pa. Editorial and general offices, 33 West 39th St., New York 18, N. Y. Subscriptions $8.00 per year in the United States and possessions; foreign countries $10.00. Single copies, nonmembers $1.50; members $1.00. Second-class privileges authorized at Easton, Penna. This publication is authorized to be mailed at the special rates of postage prescribed by Section 132.122. Copyright 1959, by the American Welding Society. The Society is not responsible for any statement made or opinion expressed in its publications. Permission is given to reprint any article after its date of publication provided credit is given.

PRESS-TIME NEWS ... about ... People ... Welding ... Products

AWS Releases New Soldering Manual

The AMERICAN WELDING SOCIETY recently announced the publication of the first comprehensive manual on soldering ever published. Containing 180 pages, 81 illustrations and 34 tables, the book completely covers all phases of soldering, combining the theoretical with the practical.

The twenty-one chapters deal with the following subjects: principles of soldering; solders; fluxes; joint design; precleaning and surface preparation; equipment, processes and procedures; flux residue treatment; inspection and testing; copper and copper alloys; steel; coated steels; stainless steels; nickel and high-nickel alloys; lead and lead alloys; aluminum and aluminum alloys; magnesium and magnesium alloys; tin; cast irons; precious metal coatings; printed circuits; and safety.

The manual is equally useful to the amateur and the professional. The practical man will find the latest techniques described and clear indications given when to solder, what to solder and how to solder. The engineer who wants to know the principles involved in setting up sound soldering schedules will find the information in detail. All phases of soldering are described including the new techniques which have been developed for miniaturization in the electronic field.

Chemical composition of hundreds of solders are given, together with flux formulations for the various metals. Copies may be had from the AMERICAN WELDING SOCIETY, Department T, 33 W. 39th St., New York 18, N. Y., at a list price of $5.00.

Canadian Group Names Biskup

The Canadian Welding Bureau has recently announced the appointment of Joseph T. Biskup as chief welding engineer with headquarters at the Bureau's offices 1393 Yonge St., Toronto.

Until recently, Mr. Biskup was assistant chief engineer of Disher Steel, Division of Dominion Structural Steel Ltd. where he supervised the welding of a number of outstanding buildings in the past few years. These included the Shell Tower on the grounds of the Canadian National Exhibition, the circular Owen Sound Collegiate, the Stratford Shakespearean Theatre, the Maclean-Hunter Building and, now under erection, the Sun Life Building, Toronto.

Airco Awards Welding Fellowship

A fourth-year Ohio State University student from Dayton, Ohio has won the first Air Reduction Co. Fellowship in Welding Engineering in competition with candidates from major U. S. and foreign welding engineering schools.

Robert Keith Fink, 24-year-old assistant in the College of Engineering's department of engineering mechanics and a 1953 graduate of Dayton Fairview High School will receive a $2400 stipend for the 1959–60 academic year to help finance his final year of the five-year welding engineering course.

The fellowship was established late in 1957 by Air Reduction to further advanced studies in the areas of metallurgy and is administered by the Ohio State welding engineering department.

RWMA Reports Increases

Comparative figures compiled by the Resistance Welder Manufacturers' Association revealed an increase of 39% in new business for the first six months of 1959, compared with the same period last year. Net orders for June were 10% ahead of May.

Shipments for June were also 15% above May shipments and reflected an increase of 36% over the first six months of 1958.

Backlogs of member companies exceeded $8\frac{1}{4}$ million for the fourth consecutive month.

Ultrasonic Welding for Containers

Advances in high speed ultrasonic seam welding of aluminum holding special promise for container and packaging manufacturers were announced recently by Aeroprojects Inc. and Aluminum Company of America.

The Alcoa-Aeroprojects cooperative program has made it possible to utilize ultrasonics for seam welding light-gage sheet and foil in thicknesses ranging from 0.006 to 0.010 in. at speeds in excess of 30 fpm. Speeds above 100 fpm. have been

demonstrated using somewhat thinner materials.

Only three months ago Alcoa and the West Chester, Pa., firm jointly announced the development of ultrasonic splicing of aluminum foil with the use of Aeroprojects Sonoweld machines.

The packaging industry, automobile radiator manufacturers, and the electrical industry are all considering ultrasonic welding of aluminum as a way to achieve increased production and greater economies.

Alcoa believes ultrasonic welding may provide the answer for more vigorous aluminum competition with the conventionally soldered steel can.

14 REASONS *this new "Mainliner" gives you more for your money and* MORE PROFIT ON EVERY JOB!

1. **HINGED SIDE PANELS** can be closed and padlocked in place.
2. **LARGE 25 GALLON FUEL TANK** permits extended operations. Fuel pump and fuel level gauge are standard equipment.
3. **CHOICE OF IGNITION:** either magneto with hand crank, or battery self starting systems available.
4. **AUTOMATIC IDLING DEVICE** saves gas.
5. **LONG LIFE FLEXIBLE STEEL COUPLING** has no rubber or fabric to deteriorate.
6. **ENGINE:** Dependable, economical power is supplied by the world famous water cooled 4-cylinder Willys Jeep engine. A diesel engine is also available if desired.
7. **LIGHTWEIGHT** permits quick movement from job to job.
8. **POLARITY SWITCH** lets you quickly change from straight to reverse polarity without danger of burnouts.
9. **110 VOLT DC** outlet supplies 1 KW power to operate lights and tools at the job.
10. **EXCLUSIVE WELDING HEAT CONTROL** permits up to 500 accurate settings. You can select the exact setting for any electrode or any welding position without changing engine speed.
11. **REINFORCED** welding and ground cable terminals.
12. **CONTROLLED COOLING** of all generator parts insures long, trouble-free life.
13. **250 AMP. HOBART BUILT GENERATOR** provides exceptional arc stability in all ranges—helps you do better, faster work under all conditions.

14. *The* "MAINLINER" *delivers a* HOT FAST ARC *with plenty of engine power.*

The "Mainliner" can't be beaten for fast, economical field operations. Here two welders team up to get a pipeline job done in half the time.

THE NEW "MAINLINER" is just one of the many Hobart welders that is designed to meet exacting requirements. An extremely wide variety of models in many capacities is available to exactly answer your welding needs.

200 amp. AC Power/DC Welder Combination

300 amp. DC Welder with 6 or 12 KW AC power

300, 400, 600 amp. Gas Drive Welders

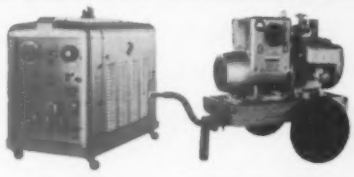
200 amp. DC "Husky Boy"

400, 600 amp. Self-Propelled "Big Wheeler"

NOW YOU CAN DO "Tig" WELDING ANYWHERE!

Here's an ideal combination that lets you do Tig Welding in the field. The Hobart PowerPak connected to the AC/AC power unit gives you all the necessary controls for welding aluminum and special metals by the Tig process.

The lightweight PowerPak unit may be taken to the work and used 100 feet or more from the generator. You can weld in hard-to-get-to locations, without making standard power line connections.



PowerPak *AC/AC Welder & Power*

HOBART BROTHERS CO., Box WJ-109, Troy, Ohio
Ph. FE 2-1223 *"Manufacturers of the world's most complete line of arc welding equipment"*

Send for this **FREE** *Catalog*

For details, circle No. 2 on Reader Information Card

HOBART BROTHERS COMPANY, BOX WJ-109, TROY, OHIO

Please send me, without obligation, complete details on the items I've checked:

☐ *"Mainliner" with gas engine* ☐ *"Mainliner" with diesel engine* ☐ *200 amp. AC Power/DC Welder* ☐ *300 amp. gas drive with 6 or 12 KW power* ☐ *300* ☐ *400* ☐ *600 amp. Gas Drive* ☐ *"Husky Boy"* ☐ *400* ☐ *600 amp. "Big Wheeler"* ☐ *PowerPak for Tig Welding* ☐ *200 amp. AC/AC Combination* ☐ *Electric Drive Welders* ☐ *AC Transformer Type Welders*

Also send me new catalog on: ☐ *welders,* ☐ *electrodes,* ☐ *accessories*

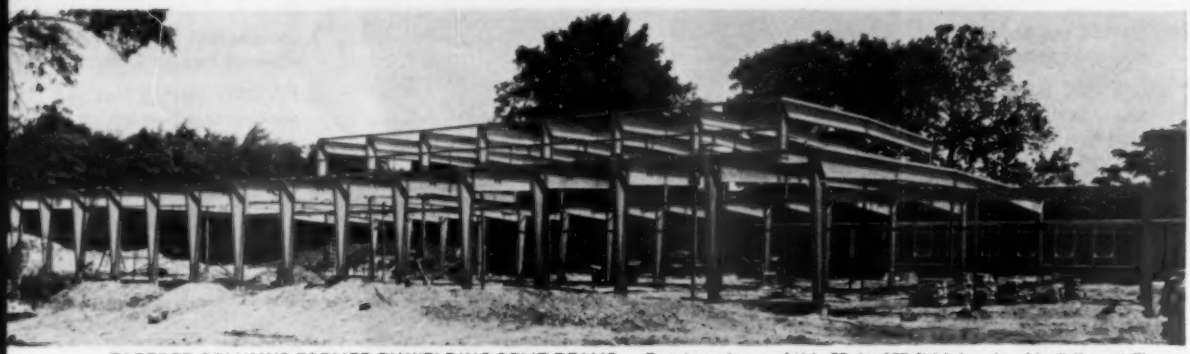
*Name*_____

*Address*_____

*City*_____ *Zone*____ *State*_____

HOBART WELDERS • ELECTRODES

WELDING ZONES



TAPERED COLUMNS FORMED BY WELDING SPLIT BEAMS. Fourteen bays of this 75- by 155-ft high school building at Finneytown in Hamilton County, Ohio, are formed by 15 rigid, arc welded frames 14 ft 3 in. high at the eaves and 15 ft high at the center. The 7-bay clerestory rises another 7 ft above the lower portion. Tapered columns and rafter end sections were fabricated at the plants to L. Schreiber & Sons Co., Cincinnati, and shop welded together at the knuckle joints before shipment to the site

REFINERY PROCESSING EQUIPMENT. Heavy refinery processing equipment leaves Chicago Bridge & Iron Co.'s Chicago plant for delivery to Magnolia Petroleum Co.'s refinery at Beaumont, Texas. From left to right, the structures are two $16^1/_2$-ft diam spherical reactors, a similar reactor 13 ft in diam, and a hydrodesulfurizer reactor 14 ft in diam and $41^1/_2$ ft long. All of the structures were shop x-rayed and stress relieved

WELDED FORMS AID TUNNEL CONSTRUCTION. Specially designed all-steel telescopic sidewall-arch forms played an important role in reducing costs of concrete construction in the $16 million Fort Pitt Tunnels, final link in Pittsburgh's 27-mile long Penn-Lincoln Parkway.

Welding played an important part in the construction of the forms, which were designed and fabricated by Blaw-Knox Company, Blawnox, Pa. The forms helped to speed setting, stripping and moving time considerably and provided a better concrete finish through highly uniform construction operations

here is an outfit which will make you proud to own it . . .

With a most acceptable price tag goes the very highest quality and safety your money can buy . . .

only $89.50

By all means — look at other "package" outfits first to make you the more certain that this one is the best for you.

• • •

here's why this combination welding and flame cutting outfit is actually the very finest your money can buy...

This new outfit, the Five Star Pak, was designed particularly for the smaller shop, for farm use, garages, the hobbyist, or any one whose welding and cutting operations are diversified and more limited in scope and metal thicknesses . . .

An economy outfit can be economical only if it will perform well and for many satisfying years to come. If it fails to meet highest standards, it ceases to merit all consideration . . .

Extendable? By all means. This Five Star Pak is amazingly versatile. It may be extended as the needs expand. Larger or smaller nozzles or tips fit the torches as do multiple flame nozzles so convenient for many brazing operations. The cutting attachment, for instance, may cut easily up to four inches of steel thickness.

You can buy with confidence from a company which has been in the business of making fine equipment for nearly fifty years.

WRITE FOR THE ILLUSTRATED FOLDER #17 which gives you all of the information you ought to consider . . .

552 DEPT.

NATIONAL welding equipment company... 218 fremont street san francisco 5 california

For details, circle No. 3 on Reader Information Card

WORLD-WIDE WELDING NEWS

By Gerard E. Claussen

DENMARK

Manual Arc Welding

Motor generators and transformers for manual arc welding with cover electrodes are discussed by H. Sejer Nielsen of Burmeister & Wain, Copenhagen (*Dansk Teknsk Tidskrift*, 83, 85–91 (1959)). A unit for shipyard use consisting of six individual transformers is described.

FRANCE

Welding Commission Meets

The Permanent International Commission on Acetylene and Gas Welding held two meetings in 1958. Progress was reported on the control of fumes in carbide furnaces and on safety in the production and use of acetylene. Papers on applications of the oxyacetylene flame competing for the Commission's prize must be submitted by Dec. 31, 1959.

Resistance Welding

Soudages et Techniques Connexes, Vol. 13 (1959) contains a description by representatives of Simca of novel methods of resistance welding and materials handling in a French automobile factory. The total installed resistance welding power is 60,000 kva.

Proper Power Supplies

In a survey reported in *Soudages et Techniques Connexes*, Vol. 13 (1959), of recent developments in continuous electrode arc welding by H. Gaubert of the French Institute of Welding, the importance of constant potential power supplies to prevent excessive variation in arc length is emphasized. The application of cored electrodes for electroslag welding is mentioned, as well as the advantage of warm water for cooling automatic guns to avoid condensation of moisture inside the nozzle while the gun is not in use.

DR. GERARD E. CLAUSSEN is associated with Arcrods Corporation, Sparrows Point, Md.

SOVIET UNION

Electroslag Welding

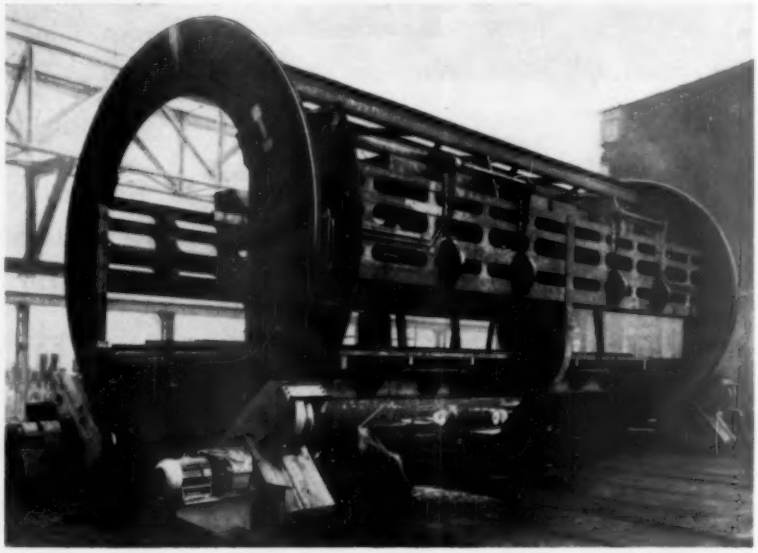
The magazine of the Kiev Electric Welding Institute in Russia for January 1959 has three articles on electroslag welding. The first article in *Avtomaticheskaya Svarka* describes the magnetic step welder A-501-M and the universal welder A535. The latter deposits bars as well as wire, and is suitable for metal thicknesses up to 32 in. There are 20 different types of electroslag welding machines available in Russia. The second article is an oscillographic study of the effect of vibrating the $^{1}/_{8}$-in. steel electrode at 1000 to 5000 vibrations per minute at amplitudes up to $^{5}/_{32}$ in. on straight and reverse polarity. As the frequency of transverse vibration was increased from 20 to 50 cycles per second, the number of droplets increased. Between 50 and 80 cycles there was an enlargement of the drops to 3 to 10 times the volume without vibration. Still further increase in frequency caused break up of the droplets, possibly due to cavitation with accompanying 20 to 25% increase in rate of deposit of electrode per ampere. The large drops reduced oxidation of alloying elements, while with small drops desulfurization is favored. The third article describes the application of the electroslag principle to heating the metal in the hot tops of ingots to prevent piping.

Welding Stainless Steel

Stainless-steel welding is discussed in four articles in the January 1959 issue of *Avtomaticheskaya Svarka*.

Work at the Lenin Polytechnic Institute in Kiev confirmed the validity of an empirical formula for

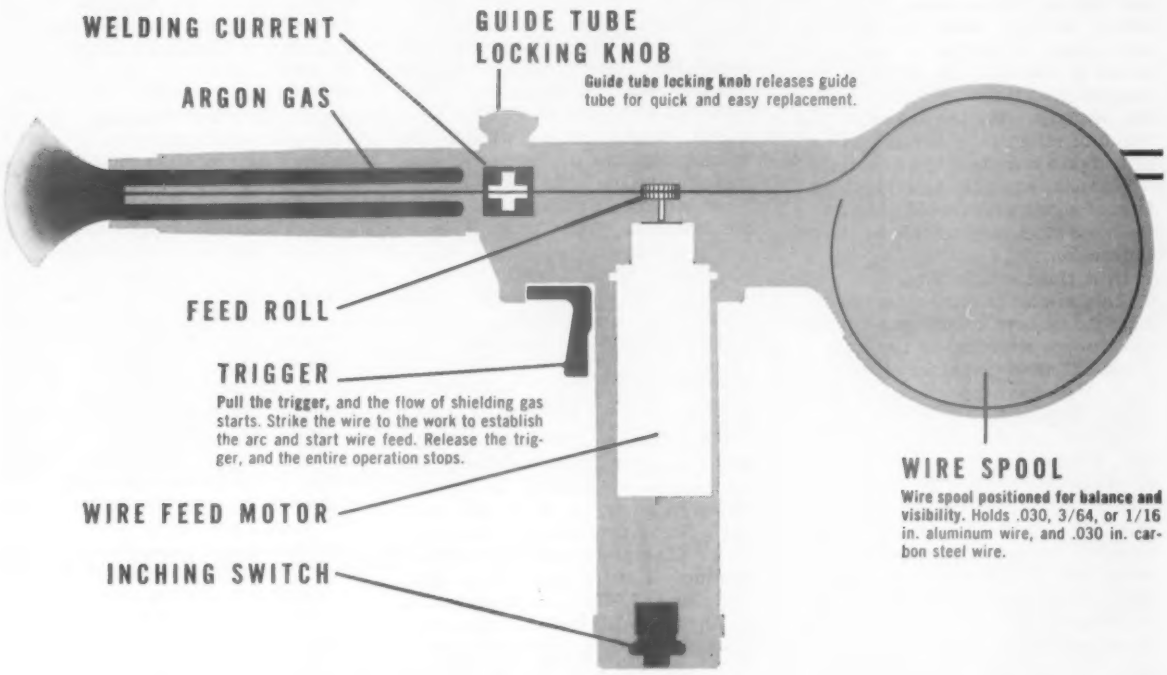
WEST GERMANY



This 99-ton capacity car unloader was built by the A. J. Pohlig A.-G. of Cologne, West Germany, for an Indian steel mill. Completely welded, except for field joints, the platform handles two standard cars, or one oversize car. (Courtesy of "Schweissen und Schneiden")

Try LINDE'S New "SIGMETTE" Torch!

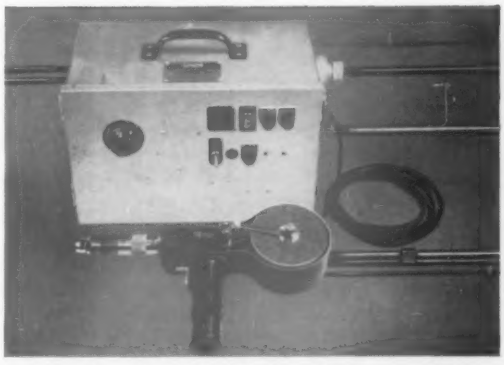
—PORTABLE, COMPACT


WELDING CURRENT
ARGON GAS
GUIDE TUBE LOCKING KNOB
Guide tube locking knob releases guide tube for quick and easy replacement.
FEED ROLL
TRIGGER
Pull the trigger, and the flow of shielding gas starts. Strike the wire to the work to establish the arc and start wire feed. Release the trigger, and the entire operation stops.
WIRE FEED MOTOR
INCHING SWITCH
WIRE SPOOL
Wire spool positioned for balance and visibility. Holds .030, 3/64, or 1/16 in. aluminum wire, and .030 in. carbon steel wire.

Here's the torch that goes to the job—lets you work in any position . . . in confined spaces . . . at distance remote from the power source!

Designed for Sigma welding of light metals, the "Sigmette" torch is compact and sturdy. Notice the thin silhouette and position of the spool for complete visibility. Torch and control are completely insulated and grounded—the operator is protected from electrically "hot" parts. And the only maintenance tool needed is a screwdriver!

Find out how Linde's new "Sigmette" torch can speed your operations, bring new economies through its advanced design features. For a free demonstration and detailed information, mail the coupon today or call the nearest Linde Office.



Complete unit—torch weighs 3 pounds, 1 oz.; control weighs 19 pounds, 2 oz.; Current rating, 125 to 200 amp.; Welding power, direct current reverse polarity

Dept. WJ-10, Linde Company
Division of Union Carbide Corporation
30 East 42nd Street, New York 17, N. Y.

☐ Please send complete facts on the new "Sigmette" torch.
☐ Please arrange to let me try it.

Name_____

Firm Name_____

Street_____

City_____ Zone_____ State_____

"Linde", "Sigmette" and "Union Carbide" are trademarks of Union Carbide Corporation.

Linde UNION CARBIDE

For details, circle No. 4 on Reader Information Card

calculating the percentage of ferrite in Cr-Ni austentic weld metal containing up to 40% Cr, 20% Ni, 15% Si, 7% Mn, 6% W, 8% Mo, 25% V, 2.0% Ti, 0.25% C.

$$\text{Magnetic saturation} = 21{,}600 - \Sigma KiMi$$

where Ki are experimental additive coefficients of the ferrite-producing tendencies of each alloying element, and Mi are the percentages of the alloys in the weld metal. The percentage of ferrite in the weld metal is obtained by dividing the magnetic saturation calculated from the formula into the experimental value of magnetic saturation determined on a sample of the weld metal.

Karasik explains the identification of sigma and carbide phases in stainless steel weld metals by X-ray diffraction.

In a third article, Iuganson adds 3% aluminum as ferro-aluminum to high-manganese submerged arc flux to improve retention of titanium in Type 321 weld metal for short-time high temperature applications (2050° F in air).

Halper and Ardentov found that Mo, V and Cb reduce the tendency of Type 308 stainless steel weld metal to intergranular corrosion after prolonged heating at 930° F. Carbide analyses indicated that the reduction in chromium content of the precipitated carbides by the alloying elements accounted for the improvement.

Inflatable Aluminum Pipe

The January 1959 issue of *Avtomaticheskaya Svarka* describes aluminum pipe for arctic and oil service which is made by welding strips 6 x 1/8 in. at the edges and inflating at site.

Low-temperature impact properties of 3 1/2% nickel steel and Type 308 stainless steel welds are presented in another article.

Also, local spectrographic analysis detected variations in carbon, manganese and chromium along a resistance butt weld in low alloy steel. If the ends of the bars to be welded were rusty, the loss in Cr, Mn and C at the joint was high.

Vibrating Electrode for Hard Surfacing

A method of hard surfacing is described by Barandv in the January 1959 issue of *Avtomaticheskaya Svarka* involving a continuous wire electrode of 0.055–0.079 in. diam vibrating axially 100 times a second and undergoing short circuiting and arcing with the base metal at each vibration. The arc is drawn under a flowing stream of water containing 20–30% glycerine and a small amount of sodium hydroxide and machine oil.

Optimum Welding Conditions Are Studied

An investigation of a high-tensile steel 3/4 to 2 in. thick described in the March 1959 issue of *Svarachnoe Proizvodstvo* revealed best results in welding at a heat input of 108,000 joules per inch. The steel had unusually high notch fatigue strength and contained 0.12% C, 1.30–1.65% Mn, 0.08–1.10% Si.

Hot cracks in submerged arc welded deposits of austenitic steel containing 0.04% C, 18% Cr, 18% Ni were caused by boron (0.014% in the electrode, 0.004% in deposit). Hot cracking was not overcome by addition of 0.042% cerium or 0.4% calcium to the electrode. Lead (0.0017%), tin (0.0016%). and sulfur increased hot cracking.

Inconel Welded by Submerged-arc Process

The February 1959 issue of *Avtomaticheskaya Svarka* described the submerged-arc welding of Inconel plates 3/8 to 3/4 in. thick with low-silica fluxes consisting of fluorspar with either alumina or sodium fluoride. Electro-slag welds were made in sections 3 3/4 in. square using an electrode of Inconel strip containing 0.78% Al, 2.39% Ti, 0.40% Fe, 0.0042% B, 0.04% C, 0.26% Mn, 0.22% Si, 0.003% S, 0.008% P, 20.91% Cr. The weld metal had almost exactly the same composition. The welds had 80 to 90% of the strength of the base metal at 1380° F.

SWEDEN

Join Ferritic to Austenitic Steel

A Swedish method for joining ferritic (2 1/4% Cr, 1% Mo) to austenitic steel (16 1/2% Cr, 13% Ni, columbium stabilized) consists of using a transition piece of high-nickel alloy (0.07% C, 3% Cr, 80% Ni, 0.7% Cb Min). An austenitic steel electrode is used to weld the nickel alloy to the austenitic steel. A nickel alloy electrode is used to weld the nickel alloy to the ferritic steel. The latter joint requires 570° F preheat and postheat at 1360° F for 1/2 hr followed by air cooling. Thermal cycle tests at 1200° F showed that the joints were free from carbon migration and from cracking due to difference in coefficient of expansion between ferritic and austentic steel. The method was described in *Soudages et Techniques Connexes*, Vol. 13 (1959).

WEST GERMANY

Static Stiffness of Welds Discussed

A paper by Prof. F. Eisele and H. Drumm of Munich in the March 1959 issue of *Schweissen und Schneiden* on the stiffness and damping of arc-welded and spot-welded joints states that static stiffness is less than calculations predict. The difference was related to the ductility of weld metal and to distortion caused by welding. Numerous graphs show the damping value of different arrangements of fillet welds. An increase in damping generally was accompanied by a decrease in stiffness. Measurements of dynamic stiffness on steel boxes 1/8 and 3/16 in. thick and 16 x 32 x 79 in. with diagonal ribbing showed that the boxes made with the thinner plate had the higher stiffness, particularly in torsion. Dynamic stiffness decreased as the length of the intermittent fillet welds was increased.

The design of draw bars to connect tracks together is explained in detail by West German post office engineers in another paper. The five design principles were: (1) no weld less than 1 1/16 inches long, (2) no groove angle less than 70 deg, (3) no intermittent welds, (4) economics, (5) smooth flow of stress for highest fatigue value.

Transformer Core Reported to Insure Safety and Reduce Weight

A new transformer "C" core for use in multiple-spot resistance welding and in resistance-welding tongs is discussed by Gengenbach in the February 1959 issue of *Schweissen und Schneiden*. Weights of older designs have been reduced to one-third through grain-oriented sheet and heat-resistant insulation incorporated in these new "C" cores. Safety is also insured by inserting a grounded foil between the primary and secondary windings.

Betatron Inspection

A 15 MEV Betatron built by Siemens-Reiniger and described in *Stahl und Eisen, 79*, 419–426 (1959), has been in use since 1954 in the Mannesmann plant in Duisburg, West Germany. A wire sensitivity of 0.6% can be achieved on a welded pressure vessel 5 in. thick with an exposure of 9 min with lead foil and fine grain (microtest) film. For a thickness of 16 in. an exposure of over two hours is required to reveal holes a few millimeters in diameter. Stereo technique is described.

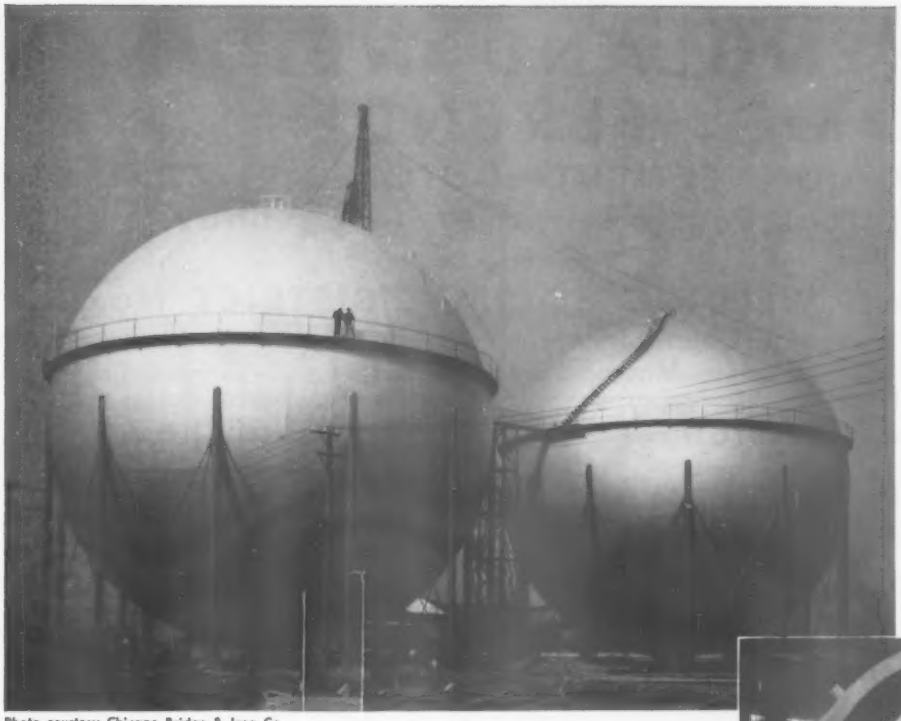


Photo courtesy Chicago Bridge & Iron Co.

When there's no margin for error...specify

ATOM-ARC ALLOYS

FOR WELDING

Low Alloy or High Strength Steels

With continually increasing fabrication costs, you can't afford a *margin for error*. Successful fabricators specify the inherent qualities of all position iron powder low hydrogen Atom Arc electrodes to reduce the unnecessary rework that chews up profits and delays jobs.

Inspection by X-ray is a requirement for most fabrications involving low alloy or high tensile steels. There is an Atom Arc alloy with the right physical properties and chemistry for welding most low alloy or high tensile steels. An electrode that deposits X-ray sound weld metal, increases the efficiency of your welding operation and lowers your costs. For complete details write for the "Handbook for Welding Low Alloy High Tensile Steels," Alloy Rods Company, Dept. 03, P. O. Box 1828, York, Pennsylvania.

Photo courtesy Baldwin-Lima-Hamilton Corp.

Atom Arc 7018 Mo
AWS-E7018-A1

Atom Arc 8018 N
AWS-E8018-C2

Atom Arc 8018 CM
AWS-E8018-B2

Atom Arc 9018 CM
AWS-E9018-B3

Atom Arc 10018 MM
AWS-E10018-D2

Atom Arc 12018 NMV
AWS-E12018-G

Atom Arc T
AWS-E11018-G

Alloy Rods Company

YORK, PENNSYLVANIA • EL SEGUNDO, CALIFORNIA

Alloy Rods Co.

QUALITY WELDING ELECTRODES FOR
Stainless Steel
Low Alloy Steels
Cast Iron
Tool Steel
Bronzes & Dissimilar Metals
Hard Surfacing Electrodes & Wires

NO FINER ELECTRODES MADE . . . ANYWHERE

For details, circle No. 6 on Reader Information Card

Fourth

NEW ENGLAND WELDING CONFERENCE

HARTFORD, CONNECTICUT—OCTOBER 21-22, 1959

Technical Session and Welding Show

Sponsored By

AMERICAN WELDING SOCIETY, DISTRICT No. 1

Boston—Bridgeport—Hartford—New Hampshire—Northern New York—Providence Western Massachusetts—Worcester

Technical Session

October 21
Rockledge Country Club
289 South Main Street
West Hartford, Connecticut

Registration at 8:30 A.M.—$3.00 for AWS Members
$4.00 for others*

"Electro-Slag Welding for Heavy Fabrication"
R. D. Thomas, Jr., Arcos Corporation

"Welding of Chrome-Moly Piping"
Jay Bland, General Electric KAPL

"Designing for Welding"
LaMotte Grover, Air Reduction Company

"Welding by Electron Beams"
Herbert Kalish, Olin Mathieson Company

"Economics in Designing and Manufacturing of Welded Fabrication"
John Mikulak, Worthington Corporation

"Plasma Technology in the Welding Industry"
James A. Browning, Thermal Dynamics Corporation

Luncheon $2.00—Steak Dinner at 6:30—$6.00
($7.00 for both including tax and tip)

The after dinner speaker will be an officer from the first atomic submarine, Nautilus, who will speak on the world's first trip under the North Pole. National AWS President C. I. MacGuffie and Secretary F. L. Plummer will be guests of honor.

* If you join the AWS during the Conference $4.00 will be credited to your initial dues.

Welding Show

October 21 and 22
Armory
836 Farmington Avenue
West Hartford, Connecticut

Tickets are available *at no charge* from all New England welding distributors and AWS members.

This is the largest Welding Show ever held in New England. Almost one half an acre of the latest and most up-to-date welding and allied equipment valued at over one-quarter of a million dollars will be on display and in operation. A partial list of exhibitors include:

Arcos, Aronson Machine, Tec Torch, Picker X-Ray, Aro-Spot Welder, United Wire, Balteau Electric, Weldma, Cortland Grinding, Alloy Rods, McKay, Cecil Peck, Brennen, Bucci & Weber, Miller Electric, Arcair, Pandjiris Weldment, Stahl Equipment, Tempil.

A. O. Smith, Induction Heating, Bernard Welding Equip, Linde Air, Cosa, Budd Nuclear Systems, P&H Harnischfeger, Weltronic, All-State, Air Reduction, United Specialties, American Chain & Cable, Presto Battery, Sperry Products, Messer Cutting, Westinghouse Electric.

Metallizing Engineering, Nelson Stud, Austin-Hastings, Whitehead Metals, Harris Calorific, Metal & Thermit, Fenway Machine, Zane Weldcraft, Smith Welding Equip, Worthington, Professional Equip, Fibre-Metal, Welsh Manufacturing, Sterling Utilities, Glendale, Heath Engineering, Handy & Harman, Liquid Carbonics, National Torch Tip, American Welding Society.

The Welding Show will be opened by the Honorable John N. Dempsey, Lieutenant Governor of Connecticut at a chain cutting ceremony at 2:00 p.m. on October 21.

Reply by October 17 — **Reply by October 17**

Advance Registration

NEW ENGLAND WELDING CONFERENCE

Mail to: Clinton E. Swift, Connecticut Welders, Inc., P.O. Box 306, Wallingford, Connecticut

Name.....Company.....

Mailing Address.....City and State.....

The enclosed check is for registration for:

Technical Session—Luncheon—Dinner—Welding Show.....AWS Members $10.00 ☐, Others $11.00* ☐
Technical Session—Luncheon—Welding Show.....AWS Members $ 5.00 ☐, Others $ 6.00* ☐
Technical Session—Welding Show.....AWS Members $ 3.00 ☐, Others $ 4.00* ☐
Technical Session—Dinner—Welding Show.....AWS Members $ 9.00 ☐, Others $10.00* ☐

There is no charge for Welding Show admission or registration. Tickets are available at Technical Session registration or from AWS members or welding distributors.

* The fee for the Technical Session for others is $4.00. If AWS membership is taken out during the Conference this $4.00 is credited toward your membership dues.

Welding—A Basic Industry

Welding has certainly come a long way from the pre-World War I days when my father and Herman Falk journeyed to Europe to buy the basic Belgium patents on cutting and welding with the oxide-hydrogen process. In those days, the gas for this process was manufactured from water. As a result, there were produced two parts hydrogen and one part oxygen. Naturally, as far as welding was concerned, this gas was rather expensive. More oxygen than hydrogen was consumed and the latter became a drug on the market. Later, when oxygen was manufactured from air, the gas cost was reduced appreciably. From these trying times, welding has grown into a tremendous tool—at work in every segment of American industry and production.

The advent of electric welding machines and electrodes made it possible to substitute structural steel for castings, thus providing an excellent means for cost reduction. Nevertheless, the electrode industry suffered many growing pains during these early years, for it took time to develop the chemical and metallurgical engineers who are so vital in the improvement of welding electrodes.

With the ever increasing use of alloy steels, the new developments in this industry are rapidly obsoleting old methods and much progress is being made toward increasing the speed of welding and, at the same time, controlling the uniformity of weld quality.

The welding industry is a process industry and requires the careful coordination of designing, production and welding research engineers in order to accomplish the desired results.

I do not know of a single industry that has made as great a contribution in the development of the machine and structural industries, and at the same time reduced costs, as the welding industry. It has grown into one of the more important basic industries of our country.

W. Harnischfeger
CHAIRMAN OF THE BOARD
HARNISCHFEGER CORP.

Welding Journal

EDITOR B. E. Rossi | ASST. EDITOR Carl H. Willer | PRODUCTION MANAGER Catherine M. O'Leary | ADVERTISING F. J. Talento | ART Gil Miller

OFFICERS OF THE SOCIETY
C. I. MacGuffie, President | A. F. Chouinard, Vice President | J. J. Chyle, Vice President | R. D. Thomas, Jr., Vice President | H. E. Rockefeller, Treasurer
F. L. Plummer, Secretary | F. J. Mooney, Asst. Secretary | E. A. Fenton, Technical Secretary | A. L. Phillips, Info.-Ed. Sec.

WELDING JOURNAL COMMITTEE
E. J. Tangerman, Chairman | J. E. Norcross, Vice-Chairman | H. R. Clauser | O. B. J. Fraser | John Haydock | C. G. Herbruck | John McCracken | A. G. Oehler | G. W. Place | A. V. Scherer | R. E. Somers | R. D. Stout

miller WELDERS

BIG TWIN
250 AC/DC

LITTLE TWIN
180 AC/DC

AND BOTH MILLERS ... *Through and Through*

BIG TWIN combination ac-dc welders work from single phase service — deliver new convenience and economy. Two a-c amperage ranges of 20-125 and 60-290 plus two d-c ranges of 18-100 and 65-290 amps master nearly every welding requirement from light gauge metal to structural pieces. Movable shunt type transformer affords infinite current adjustments. Other features include: Horizontal design for easy stacking; weather-resistant construction and Class B insulation; Miller-built semi-metallic rectifier for best d-c welding; high open circuit voltages and new weld stabilizer. This is THE all-time, all-around welder!

LITTLE TWIN ac-dc combination welder has two a-c amperage ranges of 20-115 and 60-180 plus one d-c range of 40-150. Operating from single phase service, this Miller model incorporates many design and construction features usually found only in large industrial types. These include really rugged construction, forced air cooling, new Miller semi-metallic rectifier, movable shunt type current control, new weld stabilizer and open circuit voltage in abundance. Power factor correction is available on both models. Complete specifications on either model will be sent promptly upon request.

miller ELECTRIC MANUFACTURING COMPANY, INC. • APPLETON, WISCONSIN

Distributed in Canada by Canadian Liquid Air Co., Ltd., Montreal

EXPORT OFFICE: 250 West 57th St., New York 19, N. Y.

For details, circle No. 7 on Reader Information Card

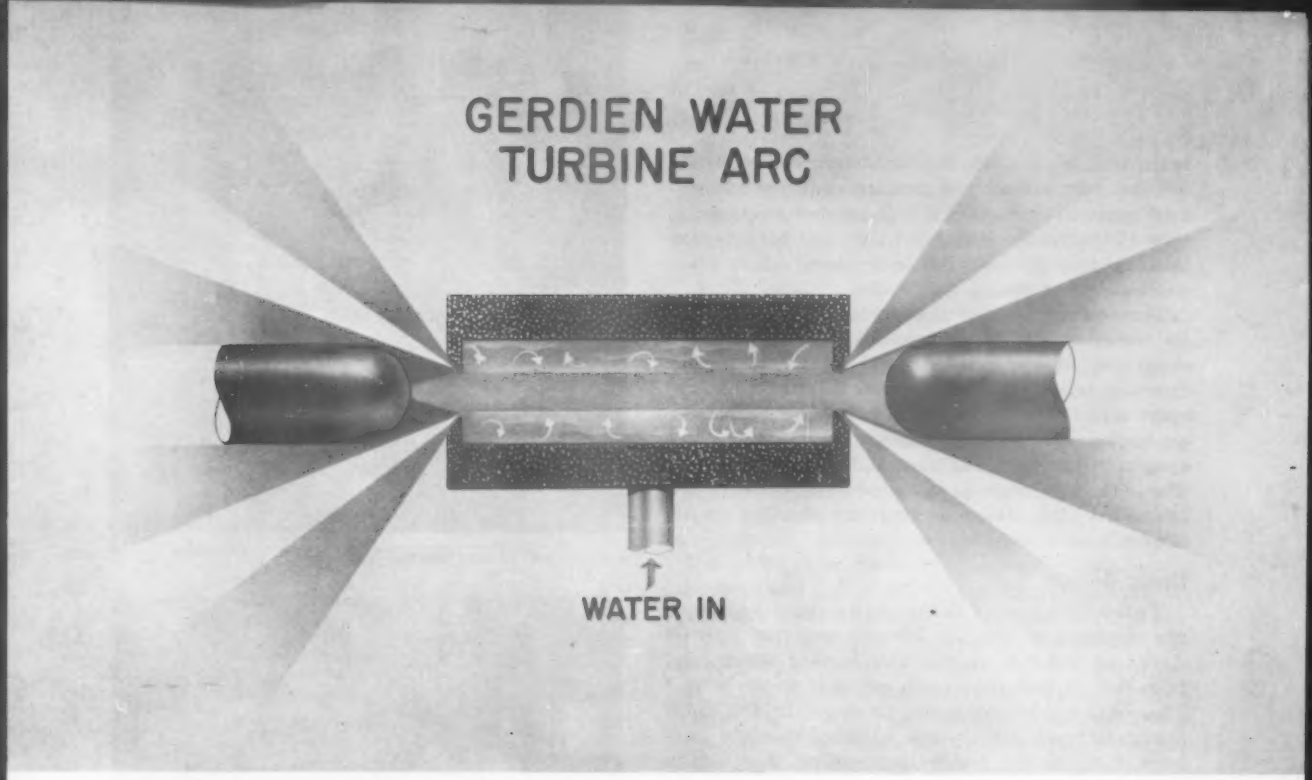


Fig. 1—Gerdien water-turbine arc

The Principles of the **Modern Arc Torch**

account for the production of a controlled-atmosphere flame several times as hot as any combustion flame

BY R. M. GAGE

In late 1955, the modern plasma jet was introduced to industry for the cutting of aluminum;[1] since then, this country has had a boom in plasma jets.[2] Because of plasma jets, the electric arc has now gained a scientific status unparalleled in its 150-year history. With reference to the term "plasma jet" —any high-current arc is comprised of plasma which is nothing more than ionized, conducting gas. When this plasma gas is jetted through a nozzle, it becomes a "plasma jet."

The discovery of the electric arc followed abruptly the invention of the battery. The practical use of the arc, however, grew little until the power-driven generator came along 75 years ago. The primitive plasma-jet device shown in Fig. 1 was devised 35 years ago by Gerdien in Europe.[3] The arc here is stabilized by a vortex of water. Jets of steam plasma squirt out both ends toward the electrodes.

Since the Gerdien arc jet was first devised, this and other experimental plasma-jet devices have been studied in Europe, mainly Germany, by Peters, Maecker and others. Temperatures up to 50,000° K have been produced by making the water vortex small so as to squeeze the arc into a small channel. Such devices have been, until recently, of academic interest only, partly because the carbon electrodes are rapidly consumed and partly because water vapor is unacceptable in most applications.

In the United States, beginning during World War II, the inert-gas tungsten-electrode process using a conventional unconstricted arc revolutionized the welding of aluminum and stainless steel because it provided long life, constant characteristics and atmosphere control.

In retrospect from the year 1959, it is notable that the modern plasma-jet torch was not developed

R. M. GAGE is Staff Engineer at the Development Laboratory of the Linde Co., Newark, N. J.

Paper presented at the AWS 40th Annual Meeting held in Chicago, Ill., Apr. 6–10, 1959.

with the advent of inert-gas tungsten-electrode welding. However, it is perhaps contrary to common sense to think that a high-current electric arc, tens of thousands of degrees hot, can be squeezed into and through a small hole in a solid nozzle without rapidly consuming the nozzle.

The introduction of the modern arc-plasma jet for metal cutting made available a long-lived tool producing a controlled-atmosphere flame several times as hot as any combustion flame. Since the spurt of activity on plasma jets began, the plasma jet has been proposed for many things. A principal spur in this interest was the missile reentry problem. The plasma jet is uniquely suited to simulate, in the laboratory, the severe heating and ablating conditions of nose-cone reentry.

Basic Design

Two basic types of the modern plasma-jet device are sketched in Fig. 2. The "transferred" arc is shown at the left where, after leaving the nozzle, both the arc and gas stream continue to the work.[4] This is the basis for metal cutting. In the torch shown to the right, the arc is forced into and, perhaps, through the nozzle by the flow of gas; the arc ends on the nozzle and the hot gas keeps going.[5] This so-called "nontransferred" arc torch is the basis for plasma arc-plating processes.

The physical essence of the modern plasma-jet device is that the electric-arc column is forced to operate within a small diameter tube through which go both a part of the arc and a flow of gas. By making the nozzle small relative to the normal unconfined arc, the arc is made to fill a substantial part of the nozzle. Thus, a substantial part of the gas flow through the nozzle must also be through the arc. The contrasting case is where the arc diameter is normally smaller than that of the nozzle. Under this condition, very little gas is forced through the arc.

The advantages provided by arc constricting nozzles include:

1. Arc-flame stability—The plasma from a constricting nozzle goes in the direction it is pointed, even at relatively low gas flows.

2. Concentration of power—This is most obviously important in metal cutting where it is desired to make the kerf as narrow as possible.

3. Concentration of momentum—The value of this is apparent in accelerating metal particles to be plated or in ejecting molten metal from a cut.

4. Heating of gas and powder—Material passed *around* an arc will be heated very little, as compared with material forced *through* an arc.

All of these properties of an arc in a nozzle are at a maximum when the nozzle is made as small as practicable for a given use. An example can be taken from tungsten-arc cutting practice (Fig. 3). The current can be 500 amp, the voltage 100 v, and the gas flow 100 cfh. Fifty kilowatts are delivered through the nozzle at an average gas temperature of 10,000 to 15,000° K. For a $^1/_8$-in. diam nozzle, the power concentration is 3 megawatts per square inch; the velocity of the gas is about equal to sonic velocity at these high temperatures, which is several thousand miles per hour. This concentration of power and momentum produces clean, narrow cuts in 1-in. thick aluminum at a rate of hundreds of feet per hour.

Fig. 2—Two types of plasma-jet torches

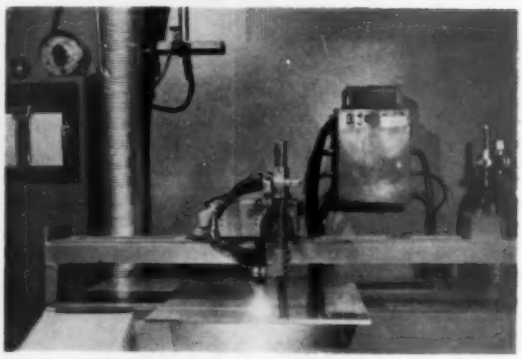


Fig. 3—Equipment for tungsten-arc cutting utilizing plasma-jet principle

Physical Principles

How is the nozzle material of an arc-plasma torch able to withstand arc temperatures? The answer, of course, is that it does not. In a properly designed torch, the arc column does not touch the nozzle. The nozzle wall is cold relative to the arc. Surrounding the arc column proper and adjacent to the nozzle wall is an annular layer of cooler gas having a very steep radial temperature gradient. At low gas flows through the nozzle, the cool layer results from the radial flow of heat to the nozzle. At higher gas flows, much of this radially flowing heat is swept out by the flow of gas before reaching the nozzle wall.

The relatively cool nonconductive gas at the wall forms a tube of electrical and thermal insulation to stabilize the arc column centrally in the nozzle and protect the nozzle. This insulation is effective to the extent that in metal-cutting operations, for

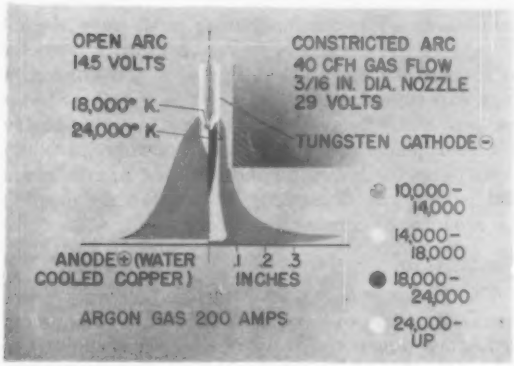


Fig. 4—Arc temperatures

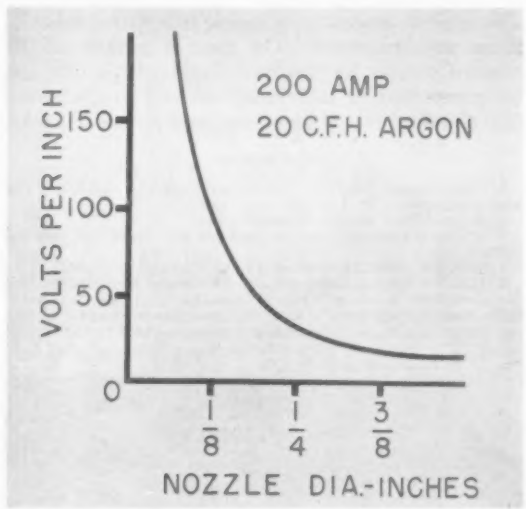


Fig. 5—Voltage gradients in various size nozzles

Fig. 6—Modes of electrical-conduction nozzles

example, less than 10% of the total heat goes to the nozzle; this is mostly radiation from the arc. A gross breakdown of this film of insulation, resulting either from current overload or excessive gas turbulence in the nozzle, produces nozzle failure.

When an electric arc is constricted in a nozzle, its voltage gradient increases significantly. Thus, when an arc is squeezed, its cross section gets much smaller. Therefore, the column resistance is high relative to an unconstricted arc. A given current through this high resistance produces a high voltage and power dissipation, and increases the arc temperature. This is shown in Figs. 4 and 5.[6] Figure 4 compares the temperatures of two different arcs in argon. The left half is a normal unconstricted arc; the right half is constricted by a $^{3}/_{16}$-in. diam nozzle. Even at this modest constriction, a 30% increase in temperature and a 100% increase in voltage are observed. The maximum temperature of this constricted arc is 24,000° K, which is 40,000° F. Figure 5 gives arc-column voltage gradients in a nozzle vs. nozzle diameter for a series of different nozzle diameters. The 80 v per inch in a $^{1}/_{8}$-in. diam nozzle is nearly ten times greater than that of an otherwise comparable unconstricted arc.

In a nontransferred arc in which the nozzle, itself, is a primary electrode, the arc current must somehow go through or around the "insulation" formed by the cool gas annulus. In Fig. 6 the arc shown to the left goes out from the nozzle and then comes back to the face of the nozzle, thus getting around the cool gas annulus. High gas flow and short nozzles favor such operation. The nozzle on the right in Fig. 6 is sufficiently long so that the arc is entirely contained within the nozzle. The current does not all go to one point but is distributed along a part of the nozzle length. There are two ways in which the current gets through the "nonconductive"gas annulus: First, it can puncture the annulus in one or many discrete anode spots much like lightning jumps form the clouds to earth; second, the electrons can get to the nozzle by diffusely drifting through the thin "cool" layer. The nontransferred type of torch operation in which the nozzle is the anode is inherently severe on the torch nozzle. However, nontransferred torches can be operated quite successfully at currents up to 5000 and more amperes. The problem is one of dispersal of the anode spots with regard to both area and dwell time.

Operational Variables

Any gas or mixture of gases which does not attack the tungsten cathode can be used in the plasma-jet torch. These include the rare gases, argon and helium, plus nitrogen and hydrogen. The diatomic gases, particularly hydrogen, have good heat-transfer characteristics to a workpiece but are often metallurgically unacceptable.

Which torch is used for what? In the cutting of metals, it is usually best to put the work in the circuit as the anode. It is desired to melt the work,

and transferred-arc operation does this with greatest efficiency. In many coating processes, however, the work should remain as cool as possible. The arc has done its work in the torch in heating and accelerating the particles of the coating material. Hence, the arc is ended on the nozzle. In melting ceramic material, the arc anode is usually on the nozzle because the work is a poor electrical conductor. However, in the manual cutting of relatively thin metals, a transferred arc will be extinguished if progress along the line of cut is too slow and, since cutting is so rapid, the somewhat lesser efficiency of the nontransferred method is of no consequence.

The practical range of power for continuous operation of plasma-jet devices is as great as that for normal unconstricted arcs. This range is from a few watts, such as might be used for welding very thin material, up to at least a few megawatts such as might be used to test missile designs. Full-scale simulation of missile reentry would require hundreds of megawatts, which is about equal to the capacity of the largest modern generators. This is a worthy and seemingly attainable goal.

The torches which have been discussed here are rather simple. The more elaborate torches for wind-tunnel operation require not only special shielding for protecting the cathode from air, but also are often combined with extensive vacuum systems on the down-stream side for high-altitude simulation. Torches for plating must have shields to protect the electrodes from the powder particles in the gas stream. The design of a nontransferred type experimental torch is given in Fig. 7. Shown are provisions for pilot arc starting, supplementary electrode shielding, and gas and powder introduction. The torch has an independent nozzle anode and is thus not dependent on gas flow for pushing the arc into the constricting nozzle.

Conclusion

The modern plasma jet, which is now only a few years old, seems to have been born at the right time in history to grow with the increased needs of the space age for high-temperature reactive materials. The chemical flame, because of both temperature limitations and chemical activity, is almost totally incapable of assuming its classic role with respect to these new materials. The rate of growth of the modern plasma jet has been rapid. This rate will be accelerated as laboratory activity is translated into standard installations designed for specific jobs.

References

1. "Linde Unveils Inert-gas Tungsten-arc Cutting of Aluminum" THE WELDING JOURNAL, **34** (11), 1097–1098 (1955).
2. *Aviation Week*, **69**, No. 15, 48–65 (1958).
3. Historical summary given in *Handbuch der Physik*, **22**, 299–303 (1956).
4. U. S. Pat. 2,806,124, assigned to Union Carbide Corp. (1957).
5. U. S. Pat. 2,858,411, assigned to Union Carbide Corp. (1958).
6. Data from Speedway Research Laboratory of Linde Co., Div. of Union Carbide Corp. (Refer to H. N. Olsen papers presented at 10th and 11th Annual Gaseous Electronics Conferences, 1957 and 1958).

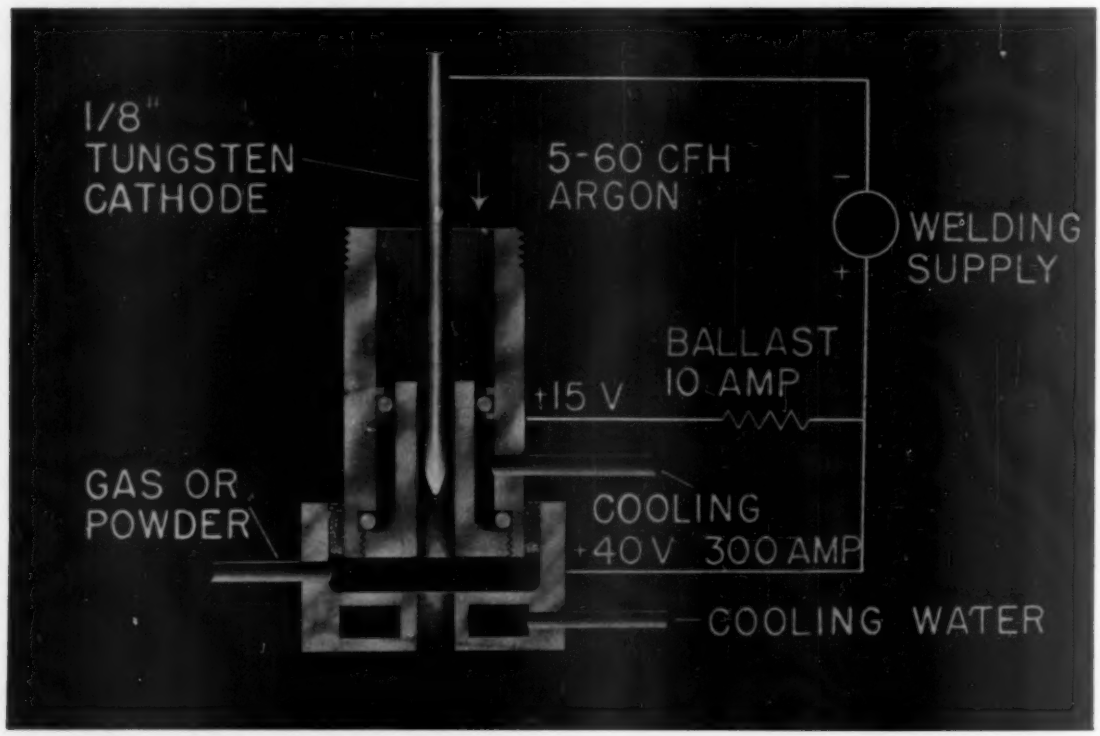


Fig. 7—Cross section of experimental nontransferred-arc torch

Fig. 1—
Chemically milled
tank-skin section

BY RUSSELL MEREDITH

With proper equipment, tooling and procedures, thin-gage large assemblies can be fabricated by

Fusion Welding

Precipitation-Hardening Steels

This paper deals with the design, manufacture and test data on the fusion welding of 17–7 PH and 17–4 PH precipitation-hardening stainless steels, accumulated over a period of five years at North American Aviation Missile Division, Downey.

Welding was used extensively in the fabrication of the missiles because the major part of the missile contains fuel and must be liquid tight. The use of sealants means extra cost and weight and, in general, has not been too successful. Large, flimsy assemblies in gages as thin as 0.015 in. thick, considered impossible to fusion weld in the past, have been welded with excellent results.

The success of this work is due largely to the fact that it was learned early in the preliminary investigations that, in order to maintain quality of welds, free from distortion, automatic welding and good tooling are required.

Materials

In selecting materials to withstand speeds encountered in today's missiles, it is necessary to choose a material that retains good strength at elevated temperatures.

Among several high-temperature materials investigated, 17–7 PH and 17–4 PH were chosen because of their properties at room and elevated temperatures. Recently, other new materials such as 15–7 Mo and AM350 have been developed with superior elevated-temperature properties.

Metallurgy

Heat Treating

Skins. Because of the size of the missile and the thin gages used, heat treating after welding would be impracticable because of excessive distortion that would occur. Thus, except for fittings and accessories such as tanks and aerodynamic surfaces, the material was heat treated prior to welding and the welds placed where lower allowables could be tolerated. In some cases, where high strengths were required, extra thickness was provided at the weld zone. This is shown in Fig. 1.

17–7 PH. The heat treatment used on the 17–7 PH sheet material was the TH1075–1900° F anneal, 1400° F transformation and 1075° F hardening. Room temperature tensile strengths were 170–190 ksi.

RUSSELL MEREDITH was formerly associated with North American Aviation; he is now a Consulting Engineer in Newport Beach, Calif.

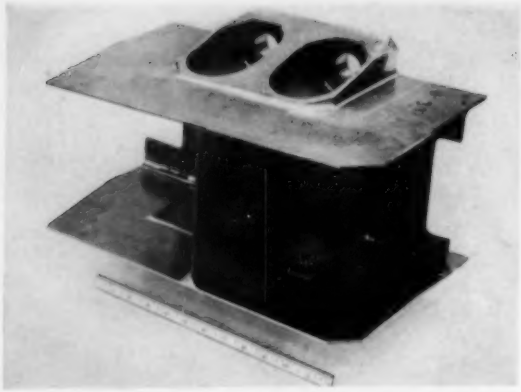


Fig. 2—Wing-attachment fitting (17–4 PH)

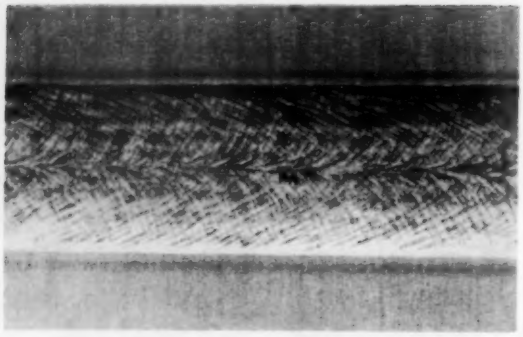


Fig. 3—Single-pass weld, $^{5}/_{8}$ in. thick plate

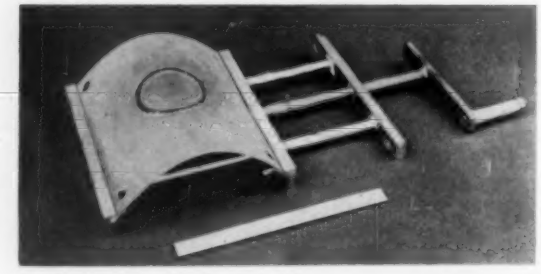


Fig. 4—Crack-sensitivity test plate

Another type of treatment used on thin sheet-metal components, such as skins, prior to welding was termed "SA," meaning stretched and aged. It involved stretching the material a predetermined amount and then age hardening at a temperature from 850 to 950° F, resulting in tensile strengths of 170–190 ksi.

17–4 PH Fittings. Because of the low transverse properties of 17–7 PH bar stock, fittings such as wing attachments, landing gear, longeron, bulkhead and other forged and machined and welded fittings were made of 17–4 PH and heat treated after welding. One such fitting is shown in Fig. 2.

17–4 PH Heat Treatment. Heat treatment used on the 17–4 PH fittings was H950–1900° F anneal,

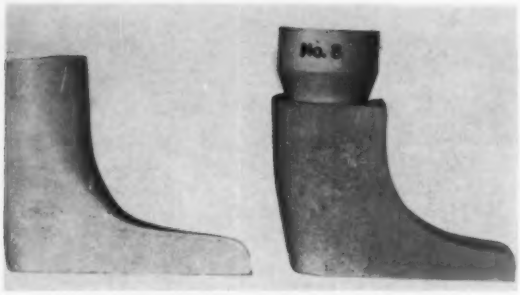
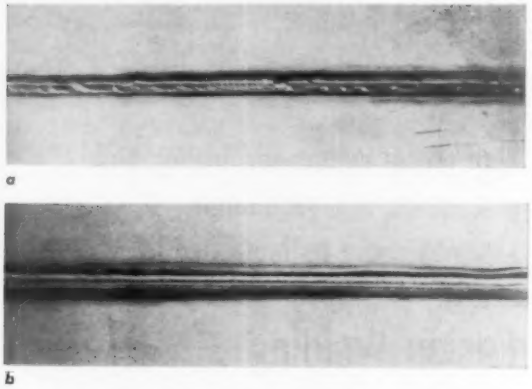


Fig. 5—"NO OXYGEN" ("NOOX") cup



a

b

Fig. 6—Automatic gas-shielded tungsten-arc welds (17–7 PH)

followed by a 950° F age-hardening treatment. Tensile strengths of 170–190 ksi were obtained.

Welding Parameters

Weldability. Weldability as defined by the AMERICAN WELDING SOCIETY covers a large scope. The AWS states that the weld shall have properties that will function satisfactorily in the intended service or use. There are many facets, however, to be considered in order to make welds which will perform satisfactorily in the service intended, such as:

Welding rods, filler-metal wires and electrodes

Welding techniques such as preheat, postheat, skip, backstep, multiple pass vs. single pass, etc.

Welding characteristics such as flow characteristics—high or low surface tension, crack sensitivity, etc.

Filler Metal. 17–7 PH filler wire was used on all of the automatic gas-shielded tungsten-arc welds. 17–4 PH rods and electrodes were used on manually welded fittings of 17–4 PH and 17–7 PH welded to 17–4 PH.

Welding Techniques. Preheating and postheating are not required except in isolated cases of varying thicknesses or highly restrained welds.

In the early stages of the welding program, welding

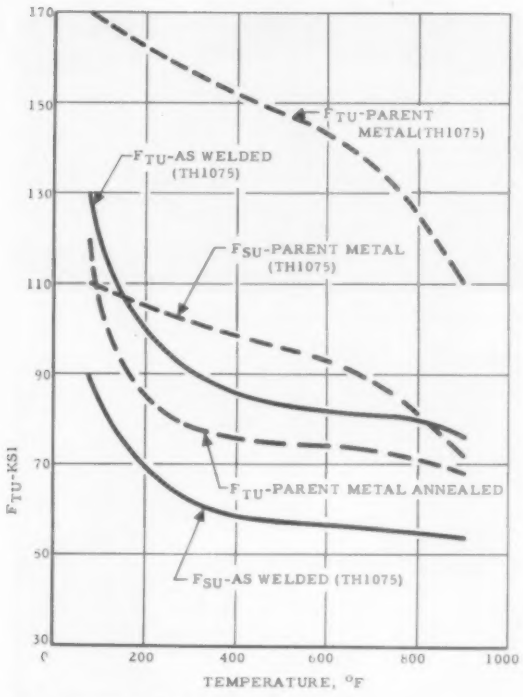


Fig. 7—Design allowable for fusion welds

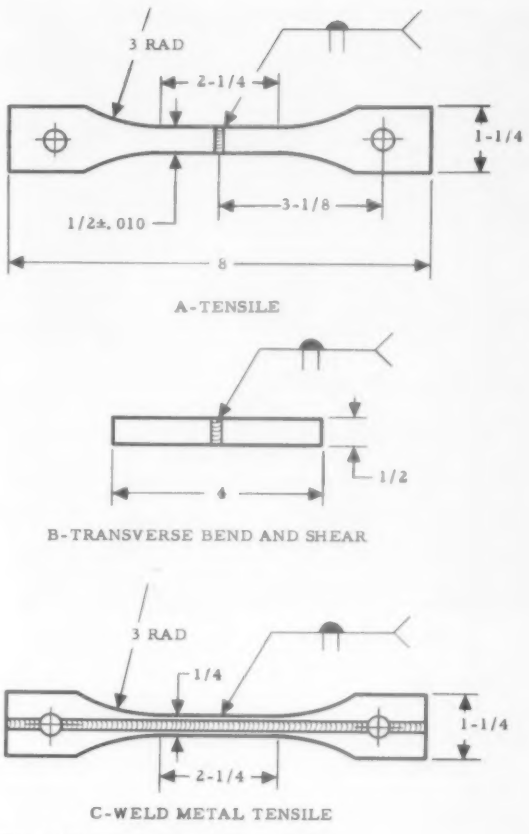


Fig. 8—Standard weld-test specimens

of 17–7 PH $^1/_8$ in. thick and over was done by using "V" or "U" scarfs and multiple passes. However, later it was learned that single-pass welding with no scarfing not only is less costly to perform, but has other advantages such as better-weld quality and less distortion of the joint. Such a weld is shown in Fig. 3.

Crack Sensitivity. Crack-sensitivity tests were made. After considering several recommended crack-sensitivity test methods, it was decided that the circular-patch restrained-test plate had the most desirable points. This is shown in Fig. 4. In addition to the normal welding residual stress, the plates were bent to impose an additional bending stress. Several of these test plates were made in various thicknesses, from 0.020 to 0.250 in., and in various heat-treat combinations such as heat treat before welding, heat treat after welding and aged only; both RH950 and TH1075 heat treatments were used. All of the plates were radiographically and surface-penetrant inspected. After extensive testing for crack sensitivity, it was concluded that, within the thickness ranges tested, 17–7 PH and 17–4 PH materials are not, compared to other materials, susceptible to restrained cracking.

Welding Characteristics. 17–7 PH and 17–4 PH do not flow as readily as Type 321 or Type 347 stainless steel. However, with the aid of the extended inert shielding, such as is provided by the use of the "no-oxygen" ("NOOX") cup, welds of excellent surface appearance can be made (see Fig. 5). Welds made with and without the use of the "no-oxygen" cup may be seen in Fig. 6. Weld "A" was made without the "no-oxygen" cup and weld "B" with the "no-oxygen" cup. It was also learned that inert-gas coverage of the root of the weld would make for better quality and appearance of the weld drop-through.

Mechanical Properties

Design Allowables

Tensile and Shear Tests. The curves in Fig. 7 show the summation of test data obtained for the purposes of establishing design criteria on welded joints of 17–7 PH and 17–4 PH stainless steel. Tests were made in the as-welded condition on 17–7 PH welded to 17–7 PH with 17–7 pH filler wire, and on 17–4 PH welded to 17–4 PH with 17–4 PH filler wire, heat treated after welding. Base metal properties were also obtained.

Test Specimens. Figure 8 shows the standard fusion-weld test specimens used. "A" and "B" are tensile shear and bend specimens while "C" was used to test the strength and ductility of the weld metal and heat-affected zone.

Offset Welds

Tests were made to investigate the effect of

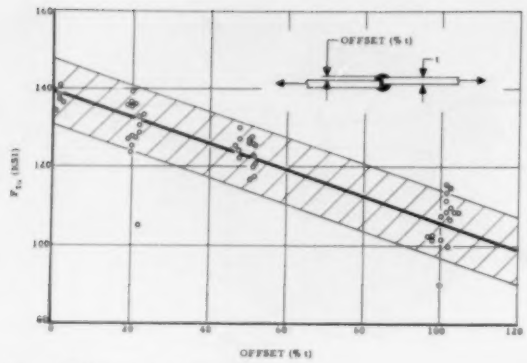


Fig. 9—Offset-weld-tests data

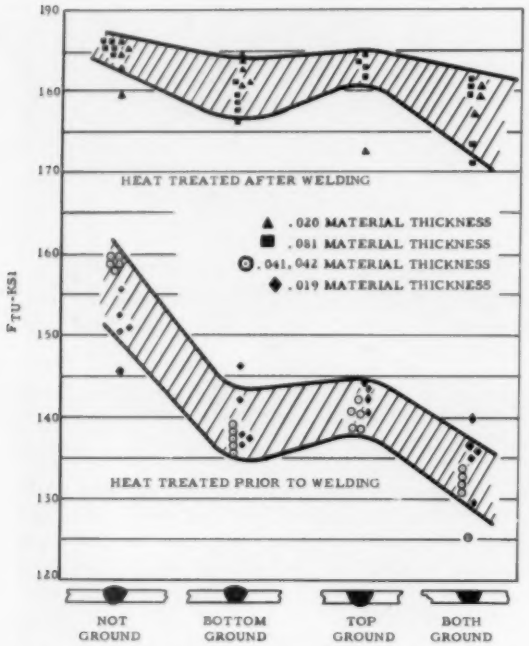


Fig. 10—Effects of grinding on weld strength

offset weld joints on weld strength. Strength values are shown in Fig. 9.

The degree of offset should not necessarily be evaluated as a percentage of material thickness, but rather as a definite measurement for each particular material, material condition and thickness.

Weld size and shape are two important factors which affect offset-joint strength. It is believed that many of the detrimental effects caused by offset weld joints should actually be attributed to cross-sectional configurations of the weld nuggets.

Weld-joint misalignment (offset) conditions are more prevalent in manually welded joints made without proper jigging than in automatically welded joints made with proper tooling. Considerable offset of butt-joint welds can be tolerated on thin-gage ductile-sheet material, such as aluminum and 18–8 stainless steel in the annealed condition.

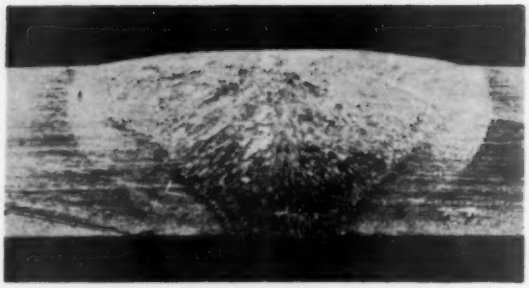


Fig. 11—Weld cross section (17–7 PH)

Fig. 12—Test tank (17–7 PH) after pressure test

Weld-Reinforcing Removal

Figure 10 illustrates the reduction in weld tensile strength when weld reinforcement is removed. It will be noted in the graph that the removal of the weld drop-through causes a greater reduction in strength than does the weld-bead removal.

Figure 11 shows a weld cross-section macrograph of a 17–7 PH heat treated to the TH1075 condition prior to welding.

As can be seen in this figure, the ferrite stringers in the dendritic grain boundaries have a vertical orientation at root of the weld nugget, and it is believed that this is responsible for lower tensile strength when the root reinforcing is removed.

Fig. 13—Pressure-vessel test (17–7 PH)

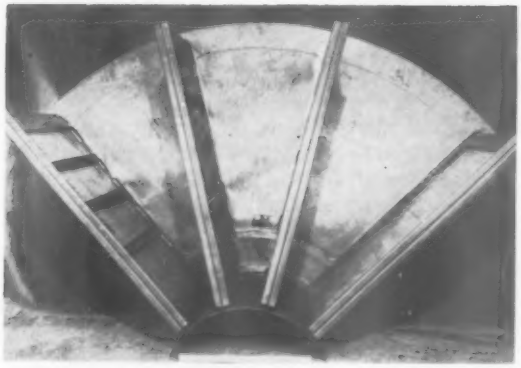


Fig. 14—Section of welded bulkhead

Because of the reduction in weld strength when welds are ground flush, no grinding of welds should be done unless called out on the drawing or otherwise specified by the engineering department.

Structural Tests

To prove the reliability of certain designs of system components and other highly loaded parts, structural tests were performed.

Pressure Vessel (Not Heat Treated). Pressure vessels were fabricated for the purpose of obtaining data on multiaxially loaded weld joints in two different conditions. The tank in Fig. 12 was welded after the material had been given a TH1075 heat treatment resulting in 170–190 ksi tensile strength. It can be noted that the failure occurred in the heat-affected zone adjacent to the weld, as was expected. What was unknown was what design allowable could be expected of a weld loaded multiaxially, as compared with the standard uniaxially loaded tensile specimens.

Other desired information obtained was the mode of failure at the intersection of the girth and longitudinal welds.

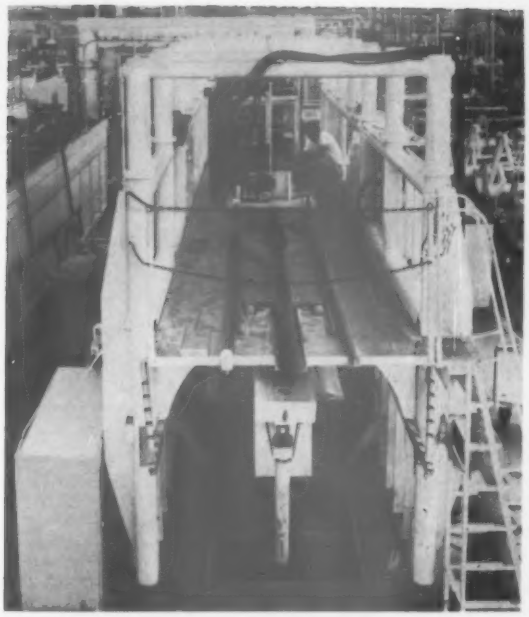


Fig. 15—Automatic longitudinal seam-welding jig

The material in the cylindrical section was 0.020 in. thick while the heads were 0.050 in. thick.

The ultimate stress in the longitudinal weld at burst was 133 ksi. Uniaxially loaded tensile specimens for similar welded specimens will run as high as 145 ksi.

Heat-Treated Pressure Vessel. Figure 13 shows the burst pattern on another tank tested to destruction. This tank was similar to the one in Fig. 12, but differed in that it was heat treated after welding to the TH1100 condition, 150–170 ksi tensile strength. The ultimate stress at burst was 160 ksi and, as can be noted, instead of the fracture following the weld as in the previous as-welded test, there were no weld failures.

Design

Bulkhead Design

In order to construct a pressure-tight tank-bulkhead assembly, a combination of chemical milling and fusion welding was employed. An assembly of such a structure is shown in Fig. 14.

The material was heat treated and chemically milled prior to welding.

Staggered intermittent welding was used to weld the stiffeners to the bulkhead.

Because of increased thickness at the weld zones, very little warpage was experienced, as may be observed.

Manufacturing

Equipment

Welding Machines. The welding machines (power

supplies) that were found to do the best job for the automatic welding of the materials previously discused were the saturable-reactor-controlled d-c rectifier-transformer type. For the manual welding of the very thin gages (0.020 to 0.040 in.), some welders preferred the a-c saturable-reactor-controlled rectifier-transformer-type machines.

17-7PH STAINLESS STEEL

Material Thickness	Groove Width ±1/6	Groove Depth ±.005	Hold-Down Spacing ±1/32
.020-.032	3/16	.010	1/4
.040-.051	1/4	.015	5/16
.064-.072	1/4	.020	5/16
.083-.093	5/16	.025	3/8
.125-.157	5/16	.030	1/2

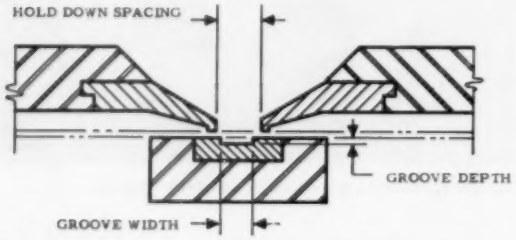


Fig. 16—Dimension for backing groove and hold-down spacing for automatic gas-shielded tungsten-arc welding

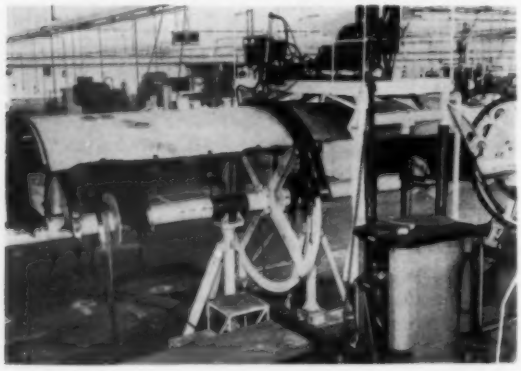


Fig. 17—Circumferential welding jig

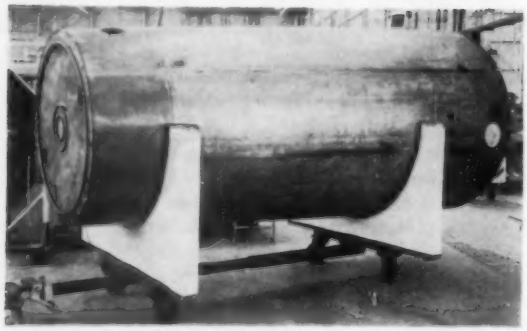


Fig. 18—Missile forward fuel tank

Automatic Longitudinal Welding Jigs. Figure 15 shows the type of jig used for making automatic gas-shielded tungsten-arc longitudinal welds on the 17–7 PH fuel-tank skins. Skin gages on the tanks were from 0.018 to 0.030 in. thick.

Rejection rates due to weld irregularities were less than one percent. All material used in construction of the hold-down fingers and backing bars was of the nonmagnetic type to prevent any possibility of arc blow. The hold-down fingers were actuated by means of a fire hose hydraulically pressurized.

Hold-Down and Backing Bars. The hold-down fingers were made of austenitic stainless steel with a continuous copper bar inserted at the tips. The backing bar was likewise stainless with a copper-bar insert. Figure 16 is a drawing showing the method of mounting the copper bars, the recommended groove dimensions and hold-down bar spacing.

Automatic Circumferential Welding Jig. Figure 17 shows the type of jig used for making the automatic gas-shielded tungsten-arc circumferential tank-skin splice welds.

As may be seen, this jig consisted of a series of wheels of different diameters to fit the various stations of the ogive shape of the tanks. The backing bar was copper mounted on steel wheels. The hold-down bars were box sections with small tygon hoses hydraulically actuating segmented copper fingers.

Fuel Tank

Figure 18 shows one of the completed integral tanks. The final close-out circumferential welds were made by resistance seam welding.

The bulkheads and corner welds and fittings were manually gas-shielded tungsten-arc welded.

Conclusions

Comparing the welding of 17–7, 17–4, AM350 and 15–7 Mo precipitation hardening materials to materials used in the fabrication of aircraft in the past, i.e., 4130, 4340, 4140, etc., it can be concluded that, from a weldability standpoint, these materials are much superior. The reasons for these conclusions are as follows:

1. Low crack sensitivity under moderate restrained conditions.
2. No preheat or postheat is required.
3. Material is corrosion resistant and, therefore, does not require corrosion-protection treatment subsequent to welding.
4. Good weld properties with low rejection rates can be obtained.

It can be further concluded that with proper welding equipment, tooling and procedures, very thin-gage large assemblies can be fabricated from precipitation-hardening stainless steels by fusion welding with good aerodynamic surfaces free from distortion.

Fig. 1—General view of 2000-watt ultrasonic spot-welding machine

Ultrasonic Welding of Aluminum

Ultrasonic spot welds in foil and sheet-gage aluminum alloys exhibit strength equal to or exceeding similar resistance welds. Joining conditions are established for many commonly used aluminum alloys

BY F. R. COLLINS, J. D. DOWD AND M. W. BRENNECKE

ABSTRACT. Ultrasonic welding is a new and promising method for joining foil and sheet-gage aluminum. In this process, high-frequency electrical energy is converted to ultrasonic mechanical energy, which introduces shear vibration between the parts being joined. A solid-state metallurgical bond is produced over about half the width of the weld with the balance being a mechanical bond.

Aluminum alloys in gages from about 0.00025 to 0.125 in. can be welded to themselves as well as to other metals. Ultrasonic welds in annealed aluminum are comparable in strength to resistance spot welds. In cold-worked and heat-treated sheet, however, ultrasonic welds are much stronger because they do not contain any low-strength cast or heat-affected zones. Weld strength increases with increasing sheet strength and gage, but is essentially independent of alloy composition except as it affects sheet strength. At the same sheet-strength level, cold-worked tempers give stronger welds than annealed or heat-treated tempers. No surface preparation is required except for the removal of heavy annealing ing or heat-treating films.

Welding conditions vary greatly, ranging from less than 100 w for 0.01 sec when welding thin foil to 4000 w for several seconds when welding 0.090-in. sheet. By far the most important joining condition is the ultrasonic frequency, which must be closely tuned to the resonant frequency of the welding array to obtain strong joints.

F. R. COLLINS and M. W. BRENNECKE are Research Engineers and J. D. DOWD is Assistant Chief, Process Metallurgy Division, Alcoa Research Laboratories, New Kensington, Pa.

Paper to be presented at AWS National Fall Meeting to be held in Detroit, Mich., Sept. 28–Oct. 1, 1959.

Introduction

Ultrasonic welding is one of the newest and most promising methods for joining aluminum. Intensive development of this process was begun in 1952. In 1955 a 2000-w ultrasonic spot-welding machine became available commercially. Since that time,

several basic improvements have been made in the equipment, and ultrasonic continuous seam-welding machines have been developed.

The basic principles and general capabilities of ultrasonic welding have been presented previously. It is the purpose of this paper, therefore, to discuss ultrasonic welding as a method for joining aluminum alloys to themselves and to other metals. Several previous publications with the same objective are listed in the references.[1–5]

Equipment

An ultrasonic welding machine consists of a variable-frequency generator, usually an electronic amplifier, and a welding head. A general view of a 2000-w spot-welding machine is shown in Fig. 1. The welding head, which is shown schematically in Fig. 2, supports the upper and lower sonotrodes, or welding tips, between which the material to be welded is hydraulically clamped. Attached to the upper sonotrode by means of a coupling bar is a laminated nickel stack, which alternately expands and contracts through magnetostriction in response to alternating-current excitation. Vibratory energy, transferred from the nickel stack to the upper sonotrode by the coupling bar, causes excursions of the welding tip in a transverse direction. This introduces shear vibration in the parts and produces welding between the faying surfaces.

The ultrasonic generator has controls for setting plate volts and grid amperes, thus permitting adjustment of the power output to any value up to about 2000 w. The frequency can be set anywhere between 5 and 100 kc. Efficient welding is obtained only if the ultrasonic generator is tuned closely to the resonant frequency of the welding array, which includes the nickel stack, coupling bar, sonotrodes and material being joined. The nominal resonant frequency of the 2000-w welding head is 15 kc. A special welding band (14–16 kc) is provided, therefore, over which the frequency can be set and controlled to about ±15 cycles. The welding head has controls for setting the clamping pressure and welding time. It is also equipped so that pressing a foot switch initiates a completely automatic welding cycle.

Experimental work was conducted using a 3-in. spherical radius hardened steel tip on the upper sonotrode and a flat tip on the lower sonotrode. Tips of other sizes or designs can, of course, be used. In fact, except for the welding of flat sheet, it is generally desirable to custom design tips for specific applications.

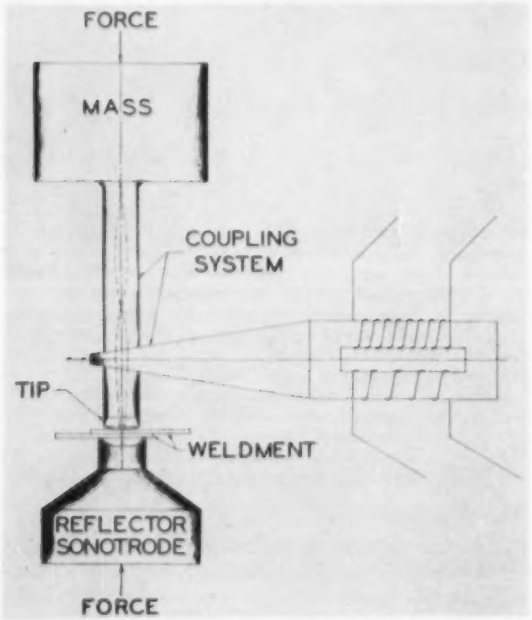


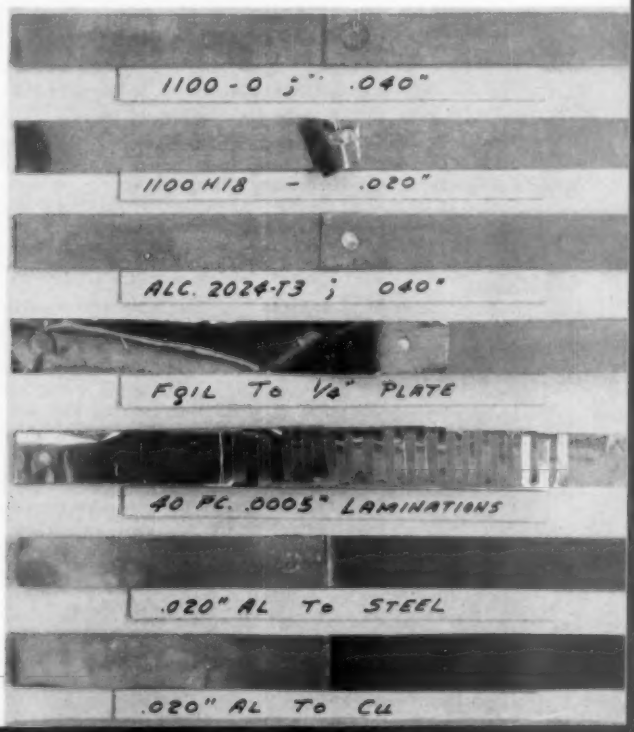
Fig. 2—Schematic drawing of welding head

Welding Procedure

In making ultrasonic spot welds, the sheets are overlapped and placed on the lower sonotrode. The power setting, clamping force, welding time and frequency are adjusted for the alloy and gage being welded. The foot switch is then depressed, initiating the welding cycle. The upper sonotrode lowers itself onto the specimen, and the clamping pressure builds up to the preset value, at which point the ultrasonic power is pulsed into the head for the selected time. The power then shuts off, and the head rises to complete the operation.

The welding conditions employed for joining aluminum and its alloys vary greatly depending upon the composition, temper, and gage of the aluminum being joined. They may range from less

Fig. 3—Ultrasonic spot welds



than 100 w for 0.01 sec when welding thin foil to 4000 w* for several seconds when welding 0.090-in. and heavier sheet. The clamping load may range from approximately 50 lb for very thin material to several hundred pounds for thicker material. The effect of these variables on the strength of ultrasonic welds is considered in a later section of this paper.

Surface Preparation

Commercially pure aluminum, aluminum-manganese alloys and alclad alloys can be welded satisfactorily without surface preparation. The aluminum-magnesium and heat-treatable aluminum alloys must generally be etched, scraped or machined prior to welding to remove annealing or heat-treating films. Once the surface has been cleaned, however, it need not be recleaned, even though appreciable time may elapse between cleaning and welding.

Ultrasonic welds can be made through many coatings; for example, certain adhesives, lacquers and papers. In general, somewhat more energy is required to weld through such coatings than to weld bare metal. Nevertheless, it is obvious that for many applications, the ability to make good welds through coatings is a distinct advantage not possessed by other welding methods.

Tip Sticking

Sticking between the aluminum being joined and the steel tips of the sonotrodes rarely occurs in the ultrasonic welding of foil and sheet up to about 0.010 in. thick. In heavier gages, however, tip sticking does occur. Unfortunately, tip sticking is most severe under conditions that give best welding. By backing off somewhat from these optimum conditions, tip sticking can be minimized.

Dressing the tips is not required unless a significant portion of the weld nugget adheres to them. This occurs rarely since it is not practical to produce welds under these conditions.

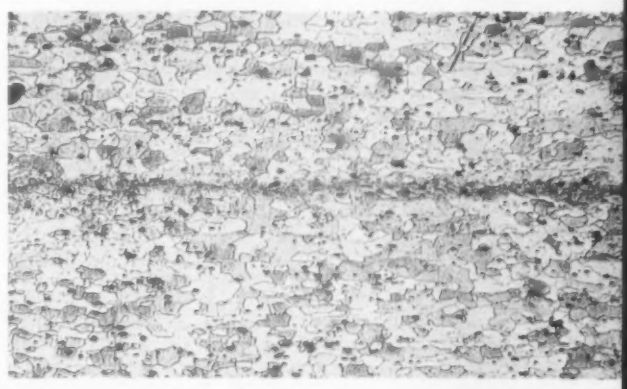
* 4000-w welding machines are now commercially available.

Fig. 4—Ultrasonic weld in 3003-H-14 alloy. × 500

Appearance of Welds

Ultrasonic spot welds outwardly look much like resistance spot welds. This is evident from the typical welds shown in Fig. 3. The diameter of the indentation left by the upper sonotrode may vary from a few hundredths of an inch to almost $^3/_8$ in. depending on the material and the joining conditions. The spot size increases with increasing clamping load, ultrasonic power, tip radius and gage of aluminum being welded, but decreases with increasing sheet strength. Also, the spot size is greater for alclad sheet than for bare sheet. In general, thickness deformation is less than 5%. For this reason, ultrasonic welds are much stronger than pressure welds, which have deformations of 40% or more.

Metallographic examination of ultrasonic welds reveals solid state bonding over approximately half the width of the weld area with the remaining area being characterized by many interlocking fragments that undoubtedly contribute to the strength of the weld. Photomicrographs of ultrasonic welds in 3003-H14 and 2024-T3 aluminum alloys are shown in Figs. 4 and 5, respectively. It is obvious from



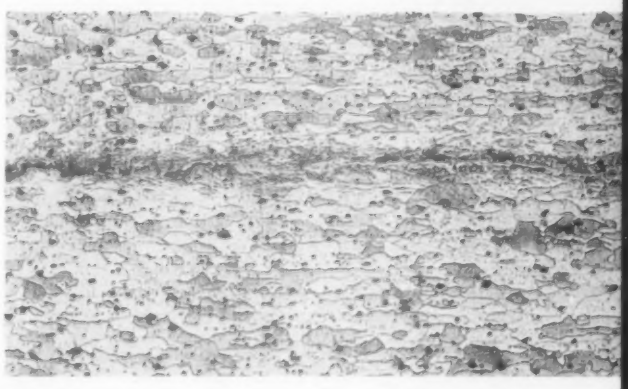


Fig. 5—(Top) Ultrasonic weld in 0.020 inch gage 2024-T3 Kellers Etch. × 150

(Bottom) Ultrasonic weld in 0.040 inch gage 2024-T3 Kellers Etch. × 150

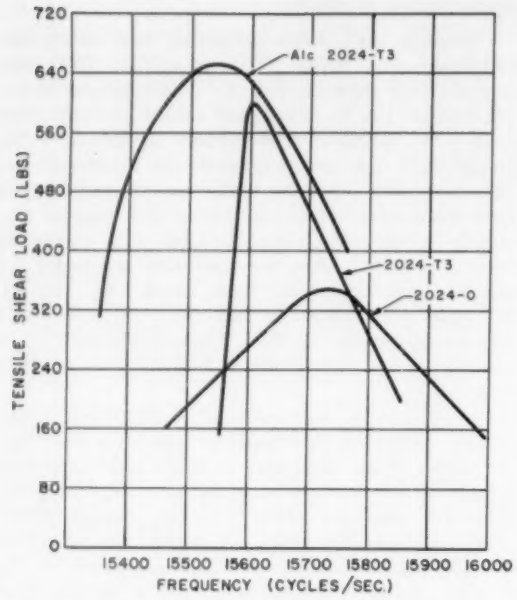


Fig. 6—Effect of frequency on strength of ultrasonic welds in 0.040 in. 2024-0, 2024-T3, and alclad 2024-T3

these photomicrographs that no melting, annealing or other heat effects occur during ultrasonic welding. Thus, it is not surprising that ultrasonic welds in cold-worked or heat-treated and aged aluminum alloys are significantly stronger than resistance welds in the same alloys. It is, of course, possible to produce heat-affected zones by severely overpowering the weld.

Thickness Limitations

Ultrasonic welding is especially suited for joining thin-gage aluminum; in fact, there appears to be no practical minimum to the gage that can be ultrasonically welded. Even foil as thin as 0.00025 in. can be readily joined. The maximum thickness that can be welded with the largest equipment commercially available today is about 0.080 in. for the high-strength aluminum alloys and about 0.120 in. for the softer aluminum alloys. Ultrasonic welding is also an excellent method for joining thin aluminum to thick aluminum. Here, only the thinner piece is subject to the thickness limitations of the available equipment. The thicker piece can be any gage. A multiplicity of thin pieces can be readily joined by ultrasonic welding; for example, as many as 20 pieces of 0.005-in. foil can be welded.

Joining Aluminum to Other Metals

Aluminum can be ultrasonically welded to many dissimilar metals such as copper, steel, titanium, brass and silver. Such welds usually require more energy to make than all-aluminum welds in material of the same gage. Some examples of welds between aluminum and dissimilar metals are included in Fig. 3.

Weld Strength

Ultrasonic spot welds in thin-gage aluminum fail when tested in tension by pulling out the spots. Similar welds in heavier gage metal fail by shearing

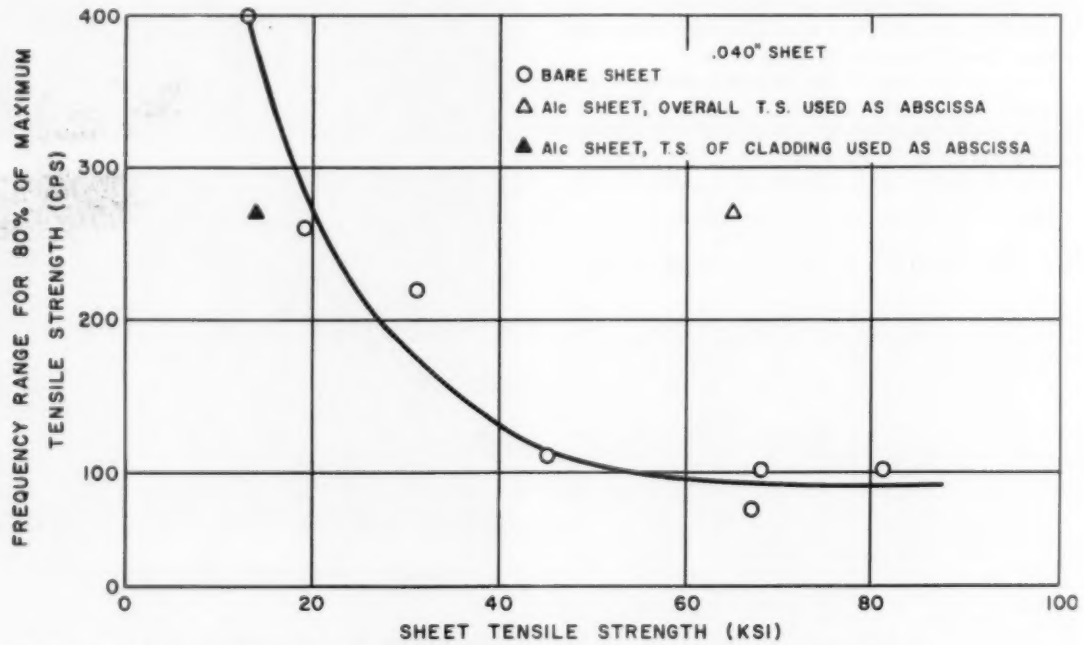


Fig. 7—Effect of sheet tensile strength on frequency range within which the breaking load is 80% of maximum

the bonds. The transition from spot-pull to shear failure varies somewhat depending upon the alloy, temper and gage, but will usually be in the 0.020 to 0.030-in. range.

The strength of ultrasonic welds is dependent upon both the joining conditions and the materials being joined. Among the joining conditions are frequency-match, hold-down pressure, and power input. The material considerations include the strength, temper and gage of the material being joined.

Joining Conditions

The strength of ultrasonic welds depends upon both spot diameter and the integrity of the bond. In 0.040-in. alclad 2024-T3 alloy, for example, a 4000-w welding machine produces stronger welds than a 2000-w welding machine. Although the smaller machine can produce welds that tear out spots when peel tested, the larger welding machine produces spots of increased diameter and higher strength.[3] To obtain the highest strengths with any size welding machine, the equipment should be operated at maximum power compatible with the thickness of the sheet being joined.

Joining conditions have relatively little effect on the strength of ultrasonic welds made in foil and sheet up to about 0.010 in. thick, at least when a high-power welding machine is used. This is so because sufficient power to make a weld stronger than the sheet can be supplied to the weld interface even though the joining conditions are not optimum. As the gage of the aluminum being welded increases, more power is required to make a weld, even at optimum conditions. Consequently, from a given capacity welding machine, less surplus power is available to offset any failure to obtain optimum conditions. As a result, the joining conditions required to make a strong weld become more critical as the thickness of the material increases. In effect, thin-gage metal can be "overpowered" by a high-power welding machine, whereas thick-gage metal cannot.

An ultrasonic welding machine must be tuned carefully to its resonant frequency to make the best welds in aluminum 0.020 in. thick or thicker. Consequently, it is not surprising that the strength of welds is less at frequencies either below or above the resonant frequency. This is shown in Fig. 6 for welds in 0.040-in. 2024-0, 2024-T3 and alclad 2024-T3 aluminum alloys. It may also be seen that the frequency spread for relatively high breaking loads, say 80% or more of the maximum, is much greater for alloy 2024-0 than for alloy 2024-T3. It has been observed that this frequency spread is a function of the tensile strength of the sheet. This is shown in Fig. 7 for 0.040-in. sheet. It is evident from this curve that frequency control is much more critical for the high-strength alloys than for the softer alloys. It should also be noted that alclad sheet does not fall on the curve when its over-all strength is used as the abscissa, but does when the strength of the cladding is used as the abscissa.

Table 1—Typical Welding Conditions for 0.040-In. Aluminum Sheet

Gage 0.040, plate volts 2400, grid amps 30, clamping load 500 lb, time 1.5 sec

Alloy and temper	Frequency		
	Optimum	80% Strength limits	
1100-0	15,850	15,600	16,000
6061-0	15,700	15,600	15,860
2024-0	15,730	15,610	15,830
5052-H18	15,620	16,580	15,690
2014-T4	15,640	15,600	15,680
2024-T3	15,600	15,580	15,680
7075-T6	15,600	15,550	15,650
Alclad 2024-T3	15,530	15,400	15,670

Since frequency control is critical, it is necessary to know that the frequency being used at any time is the correct one. There are two ways to accomplish this. The first is to operate the equipment with highly skilled personnel who can tell by "feel" when the frequency is at or near the optimum. Unfortunately, not all people acquire this feel to the same extent, and even those who become quite good at it cannot select the optimum frequency equally well day after day. Consequently, this method is of limited value. It could, however, be used when sufficient power is available so that a good weld can be made even though the frequency used is not the optimum.

A second solution would be to establish operating settings for the different alloys in the various tempers and gages. This is the best method presently available. A limited compilation of such data is shown in Table 1. Unfortunately, the design and construction of ultrasonic welding machines have not been standardized to an extent such that the resonant frequency of duplicate welding machines is exactly the same. Furthermore, different settings may be required for different tip designs. Consequently, a compilation similar to Table 1 would probably be applicable only to an individual welding machine with a given tip design.

This second procedure also requires that the welding machine, including the ultrasonic generator, be extremely stable frequency-wise. It must not drift and should be capable of being reset at exactly the same value day after day. The frequency stability of the welding machine can be evaluated by comparing a series of frequency curves made over a period of time using a hard-to-weld material such as bare 2024-T3. Such a comparison indicates that the Alcoa Research Laboratories equipment has the required stability. It should, therefore, be possible to establish and maintain proper welding conditions for any job. Using these conditions, good ultrasonic welds should be obtained unless a defect, such as a cracked joint, develops in the welding array. Such a failure would dissipate much or all of the energy being generated, thus preventing it from being available to make a weld. This would result in low properties. To insure against such

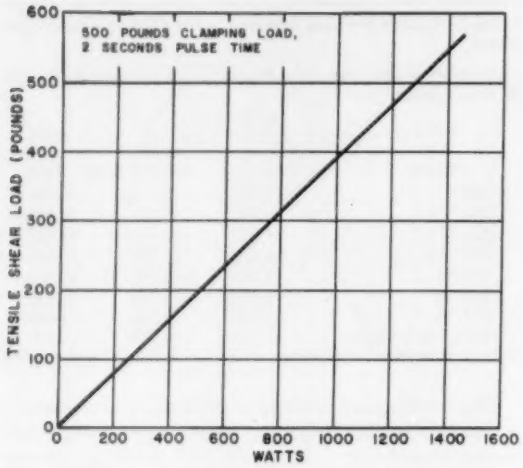


Fig. 8—Effect of power input on strength of ultrasonic spot welds in 0.020-inch 2024-T3

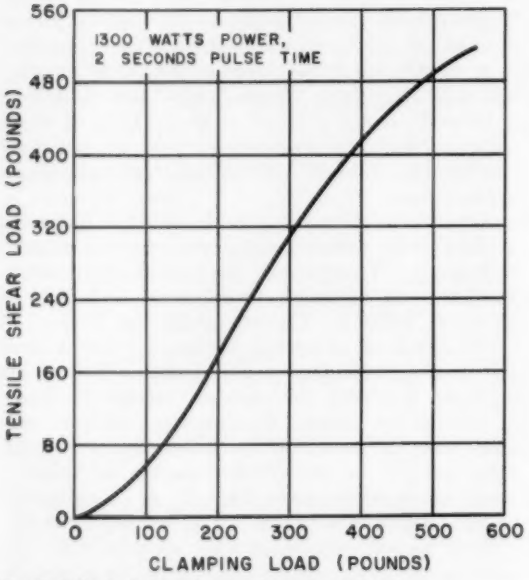


Fig. 9—Effect of clamping load on strength of ultrasonic spot welds in 0.020-inch 2024-T3

defect formation and the resultant deterioration in properties, it is recommended that tensile samples be made and tested periodically.

The strength of ultrasonic welds is also affected by power input, clamping load and time interval of the ultrasonic pulse. The relative magnitudes of these three effects on welds made in 0.020-in. 2024-T3 are shown in Figs. 8, 9 and 10, respectively. As may be seen, the weld strength increased almost linearly with both power input and clamping load. Weld strength also increased with increasing time up to about 0.8 sec. Beyond this, time had no significant effect.

The power input, time and clamping load required to make a good weld all increase with the gage

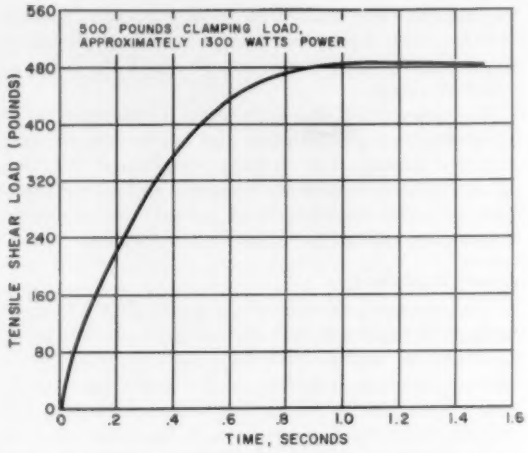


Fig. 10—Effect of pulse time on strength of ultrasonic spot welds in 0.020-inch 2024-T3

of the metal being welded. Thus, 100 w for about 0.01 sec with a few pounds clamping load would be sufficient to weld foil, whereas 1500 w for 1 sec with several hundred pounds clamping load would be necessary to weld 0.040-in. sheet.

Sheet Composition, Temper and Gage

Weld strength increases with increasing sheet strength. Alloys of equivalent strength but different composition or temper have the same weld strength. One exception is that the cold-worked tempers give appreciably stronger welds than annealed or heat-treated tempers having the same sheet strength. These effects of sheet strength and temper on weld strength are shown in Fig. 11. As may be seen, in foil gages the increase in weld strength with sheet strength is almost linear. In thicker gages, the increase is very rapid at low sheet strengths but tapers off as the sheet strength continues to increase. It is also evident from the curves that the weld strength increases with increasing gage in roughly linear manner up to at least 0.040 in., the maximum gage tested.

The curves in Fig. 11 give a good estimate of the strength that might reasonably be expected from ultrasonic welds made at or near optimum conditions using a 2000-w welding machine; for example, spot welds in 0.020-in. 2014-T6, which has a tensile strength of 70,000 psi, should have breaking loads of approximately 410 lb. The exact breaking load will vary somewhat depending upon tip design, clamping pressure, power input and a number of other factors. Ultrasonic welds reheat-treated after welding have the same properties as welds made in sheet initially in the reheat-treated temper.

Ultrasonic welds in alclad sheet develop essentially the same properties as welds in bare sheet when joining conditions are at or near the optimum. Since joining conditions are not as critical for alclad as for bare sheet, however, it is possible to achieve maximum breaking loads and better reproducibility

from alclad sheet over a broader range of joining conditions. Nearly the same effect can be obtained by interleaving 1100 alloy foil between two pieces of cleaned bare aluminum alloys.

Reproducibility

The reproducibility of ultrasonic welds made at optimum conditions is quite good; however, it is not always possible to achieve optimum conditions. It is thought, therefore, that the standard deviation between each curve in Fig. 11 and the points from which it was derived is a good indication of the reproducibility of ultrasonic welds. For the 2000 watt welding machine, this standard deviation increases almost linearly with increasing gage, varying from ±2 lb for 0.002-in. foil to about ±100 lb for 0.040 in. sheet. The deviation should be less for higher power machines.

Ultrasonic vs. Resistance Welding

Inasmuch as ultrasonic welding can be used to make essentially the same type joints as resistance welding, it is appropriate to compare these two welding methods. Such a comparison shows ultrasonic welding to have several advantages over resistance welding. Perhaps the greatest of these is that there appears to be no minimum to the thickness that can be ultrasonically welded. Other advantages are that surface preparation is simpler and longer lasting, power requirements are less, dissimilar metals can be readily joined, thin sections

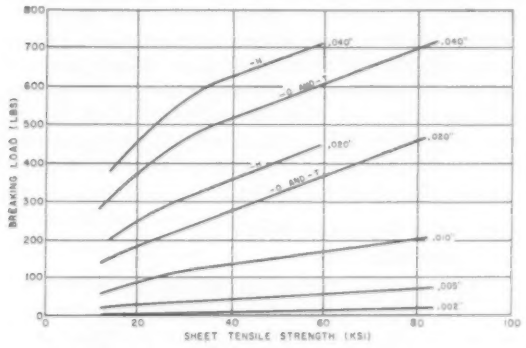


Fig. 11—Strength of ultrasonically spot-welded aluminum vs. tensile strength of sheet

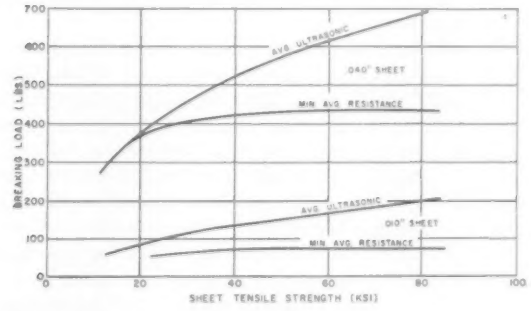


Fig. 12—Relative properties of ultrasonic and resistance spot welds

can be joined to thick sections, and there is no melted or heat-affected zone in the weld area. This latter point is especially important for alloys welded in cold-worked or heat-treated tempers. One great advantage of resistance welding is that it can be used to weld heavier-gage material than ultrasonic welding. Another advantage of resistance welding is that approximate machine settings and welding conditions have been worked out for the many aluminum alloys in different tempers and gages.

The strength of ultrasonic spot welds in aluminum alloys is appreciably greater than that required by military specifications for resistance spot welds. This is shown in Fig. 12 for spot welds in 0.010- and 0.040-in. sheet. As may be seen, ultrasonic and resistance spot welds in low-strength material, all of which is annealed, give nearly the same breaking loads. In the higher-strength cold-worked or heat-treated materials, however, ultrasonic welds are much stronger because they do not contain any low-strength annealed or melted zones.

Only limited fatigue tests have been performed on ultrasonic welds in aluminum alloys. Ultrasonic welds in alclad 2024-T3 alloy, however, show fatigue strengths at least comparable to resistance spot welds to 10^4 cycles.[4] In high load-low cycle tests, ultrasonic welds appear to be appreciably superior to resistance welds. This can probably be attributed to the absence of cast or partially melted zones, and reflects the higher static strength of ultrasonic welds.

Summary

Ultrasonic welding produces strong joints in a wide variety of aluminum alloys. Among its advantages are the ability to weld thinner gages than other well-known methods, ease of surface preparation, and the absence of melted or heat-affected zones. Power consumption is relatively low, and no power factor correcting capacitors are required.

Aluminum alloys such as 1100, 3003 and most alclad alloys can be reliably welded with minimum attention to surface preparation and operating frequency. Alloys such as 5154 and 2024 are harder to weld, requiring close control of all welding parameters, especially frequency match.

Acknowledgments

The authors wish to thank Aeroprojects, Inc., for their helpful comments during the preparation of this paper and permission to refer to their fatigue strength data.

References

1. Jones, J. Byron, and Myer, Florence R., "Ultrasonic Welding of Structural Aluminum Alloys," THE WELDING JOURNAL, **37** (3), Research Suppl., 81-s to 92-s (1958).
2. Jones, J. Byron, "Ultrasonic Welding—A New Technique Grows," *Metal Prog.*, **73** (4) 68–72 (1958).
3. Jones, J. Byron, and Potthoff, W. C., "Ultrasonic Welding Techniques", *Am. Soc. Tool Engrs. Bulletin*, Vol. 58, Book 2, Paper No. 152.
4. Koziarski, I., "Some Considerations on Design for Fatigue in Welded Aircraft Structures," THE WELDING JOURNAL, **38** (6), 565–575 (1959).
5. Jones, J. Byron and Potthoff, W. C. "Certain Structural Properties of Ultrasonic Welds in Aluminum Alloys" THE WELDING JOURNAL, **38** (7) Research Supplement, 282-s to 288-s (1959).

Dip-Transfer

Carbon-Dioxide Welding

Significance of dynamic characteristic of power supply and its effects on results in low-current CO_2 gas-shielded consumable-electrode welding are discussed

BY ROGER W. TUTHILL

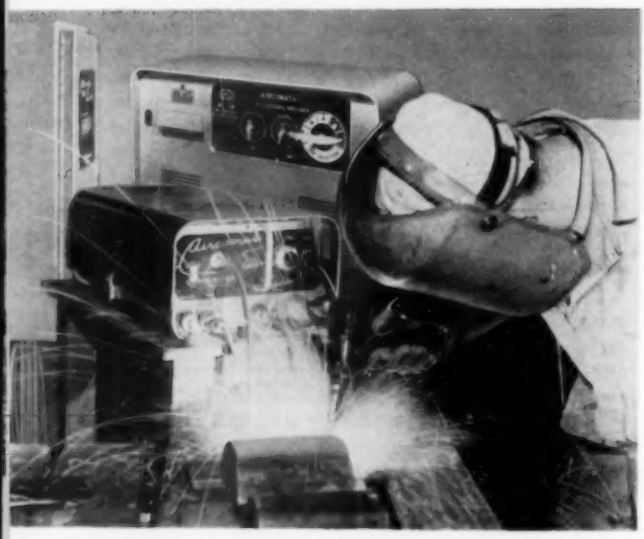


Fig. 1—Application of the Dip-transfer process for consumable-electrode welding of thin-gage steel

Introduction—Manual Welding of Thin-gage Steel

Consumable-electrode carbon-dioxide shielded-arc welding is characterized by deep penetration, high wire-feeding speeds, high current and rapid travel speeds. These features produce an ideal welding process for machine welding. Travel speeds as high as 300 ipm are being used, and speeds over 100 ipm are common. However, with CO_2 manual welding, to achieve good results, it is necessary to travel at slower speeds. This is because of human physical limitations which make it difficult to produce a high-quality weld at high travel speeds.

If the normally high travel speeds of carbon-dioxide welding are reduced, excessive penetration of the arc into the work will result. If the wire-feed speed, which controls the current, is reduced to prevent surplus penetration, then excessive spatter usually results. This excessive spatter is caused by the larger drops of molten metal which do not have uniform directional motion. Larger drops occur because of the lower current density at the electrode.

In order to make thin-gage steel, manual CO_2 welding practicable, a great deal of process research was required. Results of numerous tests led to an investigation of the equipment used to supply welding current. Just what is the role played by the welding machine in controlling the nature of the welding arc?

Prior to this research investigation on thin-gage steel welding, the work done on welding power-source design was directed toward determining the most desirable static volt-ampere characteristic to satisfy the particular arc requirements. A static characteristic is the volt-ampere relationships of welding-machine output with slowly changing requirements of current or voltage over a period of a few seconds.

Very little effort was expended toward exploring the effect of the dynamic characteristic of the power supply. A dynamic characteristic is the volt-ampere relationships of the welding-machine output with rapidly changing current or voltage requirements over periods of a few thousandths of a second.

This paper will show the significance of the dynamic characteristic of the power supply, and how it affects the results in low-current CO_2 gas-shielded consumable-electrode welding.

Electrical Characteristics of Power Supplies

The electrical factor that controls the dynamic response is the inductive reactance of the welding machine. A mechanical analogy of inductive reactance is a flywheel on a shaft. A flywheel resists any change in speed. Inductive reactance has the same effect electrically by tending to prevent an increase or decrease in current.

Three types of power sources are in general use:

1. Drooping-Characteristic Machine (Constant-Current Type). This type of welding machine is used for stick-electrode welding. In gas-shielded consumable-electrode welding, because of the high current density required, this machine does not produce a constant current but, instead, delivers a variable amount of current so as to melt the electrode wire off at the rate it is being fed. The arc length is determined by the voltage at which the machine delivers the required current and can vary for a number of reasons, such as heating, line-voltage variations, or wire-speed variations. This machine usually has

ROGER W. TUTHILL is associated with Air Reduction Sales Co., Union, N. J.

Paper presented at AWS 40th Annual Meeting held in Chicago, Ill., Apr. 6–10, 1959.

the slowest dynamic response to short circuits of any type of machine. This is true for both motor-generator or rectifier-type machines.

2. Constant Arc-Voltage Machine. This type of machine provides a relatively constant arc voltage at the required current. However, line-voltage changes or heating, and especially changes in the wire-feeding speed, prevent the arc length from remaining constant. A constant arc-voltage rectifier has the fastest dynamic response to short circuits. A constant-voltage motor generator has a slightly lower rate, but still a very rapid response under the same conditions.

3. Constant Arc-Length Machine. This type of machine produces the required current—determined by wire-feeding speed, just as with the other machines—but it does so with a rising-voltage characteristic. This "rising-slope" characteristic coincides with each specific requirement of the welding arc and results in a constant arc length; an arc length kept constant by producing increasing current with each increase in arc voltage. This machine has as fast a response as does the constant arc-voltage motor generator, but it is not as fast as the rectifier constant-voltage machine.

Arc length is a key variable controlling the quality of the weld. Porosity, spatter, undercut, bead contour, appearance and over-all quality are all affected by arc-length changes. Therefore, a constant-arc-length machine is capable of the highest-quality welding.

Since a majority of all gas-shielded consumable-electrode welding has been done without short circuits, the internal reactance of the various machines had little effect on welding. The internal reactance of the welding machine governs the dynamic response of the machine to short circuits. The main effect of this reactance or dynamic characteristic of the welding machines up to now has been in controlling the starting-current surge.

Effects of CO_2 Shielding

When CO_2 gas is used as a shielding medium in consumable-electrode welding, short circuiting of the arc by molten metal occurs quite regularly. In CO_2 welding at high current and high speed, spatter caused by these short circuits can be minimized by holding an arc that is almost wholly beneath the surface of the work. This reduces the formation of spatter and traps whatever is formed in the weld-puddle crater.

When manual CO_2 welding, at lower currents with small electrodes, the arc is short circuited for a considerable period of time. Unlike high-current welding, in low current, thin-gage welding there is little or no crater to trap spatter. Hence, another method has to be devised to eliminate spatter.

Test Results

It was recognized that the internal reactance of the welding machine would govern its specific dynamic characteristics. It was also recognized that the dynamic characteristics had a profound effect on the stability of the arc, the spatter and the general weld quality in stick-electrode welding.

Using this reasoning, a thorough study of the effect of the dynamic characteristics of power supplies on low-current CO_2 welding was undertaken. This study revealed the following: The normal drooping-characteristic stick-electrode welding machine had two or three times too much reactance; the newer low-voltage-type machines, either rising (constant arc-length) types or constant arc-voltage types, had only about one-third or one-half enough reactance.

Figures 2A, 2B and 2C show actual oscillographic photos of the three types of power sources. Notice the slow rate of rise of current with the drooping-characteristic machine, the rapid rate of rise with a constant arc-voltage machine and the proper rate of rise of the current with a controlled amount of added reactance in the constant arc-length welding machine.

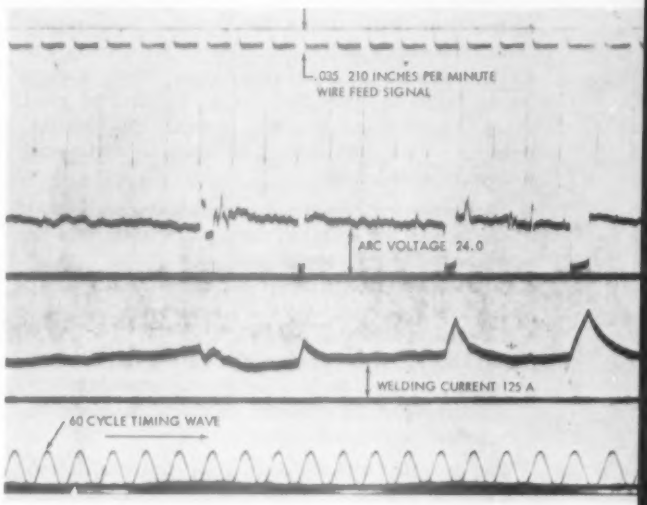
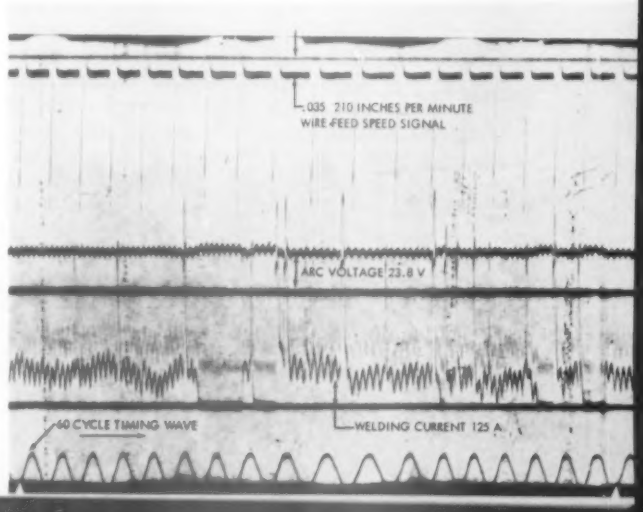


Fig. 2A—Oscillograph showing welding conditions when using a standard drooping-characteristic welding machine

Fig. 2B—Oscillograph showing welding conditions when using a constant-voltage welding machine without added reactance



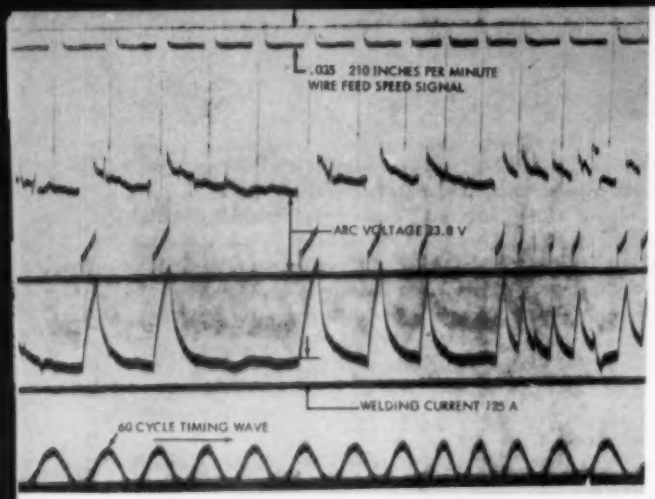


Fig. 2C—Oscillograph showing welding conditions when using a constant-arc-length, rising-voltage welding machine with added reactance

New Power Supply and Process Are Developed

A new power supply was one of the products resulting from these studies (see Fig. 1). More significant, however, was the evolution of an entirely new method of welding. A description of these developments follows. The low-current welding of steel, using CO_2 shielding, has been termed "dip-transfer" welding. This terminology is used to distinguish between the following:

(*a*) Spray transfer—many small drops of rapid free-falling metal in the arc. These drops are not visible to the naked eye.

(*b*) Globular or droplet transfer—larger drops slowly falling in the arc, which are visible to the naked eye.

(*c*) Dip transfer—no drops of free-falling metal in the arc. Nearly all metal is transferred by direct metal-to-metal contact between the electrode and the weld pool.

The action of the arc during dip-transfer welding is a unique process. While it is difficult to state the exact mechanics of the metal transfer from the electrode to the workpiece, it is possible, through the aid of ultra-slow motion pictures, to see quite clearly certain aspects of the operation. Figure 3 shows drawings, based on individual frames of the ultra-slow motion pictures, which illustrate the relationship of the electrode to the weld pool at various times throughout one complete cycle of the operation. The ultra-slow motion pictures from which these drawings are based were made at the rate of approximately 4000 frames per second. The purpose of those high-speed motion-picture studies was to provide projection at the conventional speed of 16 frames per second, to enable examination and study of individual frames.

From these figures it can be seen that immediately after the contact of the electrode and workpiece, which is usually referred to as short circuiting, the weld pool and the electrode separate and form an arc gap. The power supply is unable to sustain this arc in equilibrium, because its static output voltage is not sufficient. As a result of this low voltage, the current decays to a value below the amount required to melt the electrode off at the rate the electrode and weld pool approach one another. Consequently, the arc shortens until the pool and electrode again unite and re-initiate the cycle.

Such repetition is only possible if the current surge during the short-circuit period is sufficient to produce the necessary electrical forces to push the molten pool away from the solid wire and form an arc gap. Such an electrical force is well known and is the same force responsible for the formation of the depression directly under the arc in the more conventional types of shielded-arc welding.

This repetitive arcing and short-circuiting cycle may not necessarily depend on the electrode advancing. It has been observed that the molten pool is depressed and pushed away from the electrode end by the short-circuit current surge and that, as the current decreases after the arc is formed, this depression starts to fill in and oscillation occurs in the weld pool. As a result of this oscillation, the molten pool surges back after having been pushed away, and reaches up and again contacts the electrode to recreate short-circuit conditions.

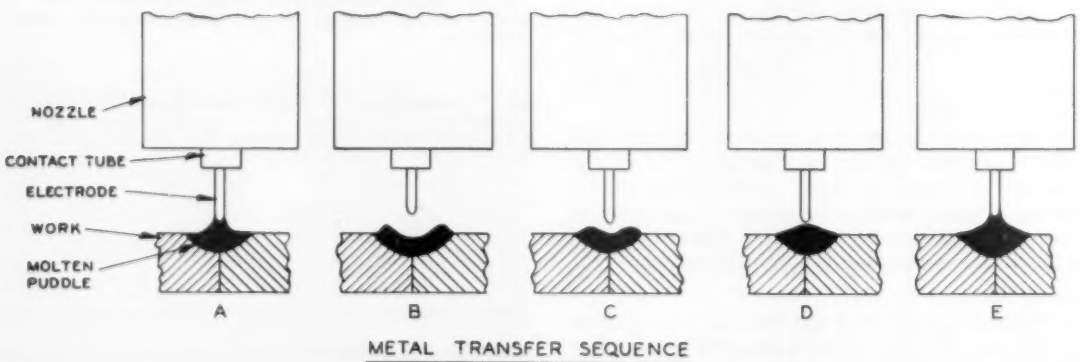


Fig. 3—Arc action as shown in slow-motion pictures

During the arcing time between short circuits, the end of the electrode is being heated by the arc and a certain amount of molten metal is formed on the electrode end. If the short circuit repetition rate is high, no visible accumulation of molten metal takes place. If the repetition rate is low (relatively), it is possible with the aid of the ultra-slow motion picture to see the formation of a small quantity of molten metal on the electrode end. The motion of this molten metal on the electrode may also contribute to the shortening of the arc gap as the current decays. In either case, the molten metal present on the electrode is wiped off the electrode each time the pool and electrode make contact. The pool oscillates as a result of the intermittent force resulting from the flow of current during both the short-circuit and arcing periods. The volume of the depression formed by the forces associated with the current flow is believed to be proportional to the square of the current.

Due to the inductance in the welding circuit, the force applied to the pool is greater during the time the molten metal is receding away from the electrode. Thus, energy is supplied to the oscillation to maintain it in motion against damping forces.

Weld-Pool Oscillation

While it is not believed essential to create an oscillating weld pool, it is believed that, in most instances, this inherently occurs. It is also recognized that several modes of oscillation can be induced and do in fact occur. The particular mode that is excited depends largely on the inductance of the circuit; a higher inductance excites a low-frequency mode of oscillation, and a lower inductance excites a high-frequency mode of oscillation. It should be noted that the resonant frequencies depend upon the dimensions of the liquid pool. These dimensions will in turn be affected by the level of welding current, the type of gas shield, the ratio of short-circuit time to arc time, and the characteristics of the material being welded.

The existence of this cyclic oscillation of the pool seems to be substantiated by the fact that in many of the tests made, the observed repetition rate of short circuits is higher than would be possible from the rate of advance of the electrode toward the weld pool alone. In all probability, the recurrence of short circuits is a combined effect of the pool coming up to meet the electrode and the electrode end advancing into the pool.

There are two basic types of operations that can occur in accordance with this new method of welding: noninterrupted current and interrupted current types. In the noninterrupted current type of operation, the short circuit condition is followed by the arcing condition which continues until the short circuit is reformed. In the interrupted current type of operation, the short circuit condition is followed by the arcing condition which continues until the arc is extinguished by the lack of sufficient voltage to support it. Open circuit conditions then exist until the short circuit is reformed. Which of these two basic types of operation occurs depends largely on circuit constants.

Since the correct motion of the weld puddle is derived from forces caused by current flow, the correct rate of build-up of current during the short circuit is very important. If the rate is too slow, the weld puddle will stop vibrating; the electrode will be preheated by the weld puddle and I^2R heating, and will melt on the end in the form of droplets. These droplets are not all projected into the puddle and, therefore, result in large quantities of spatter. This is the case with the standard drooping type power supply—it has too much reactance, which causes the current to build up too slowly.

If, on the other hand, the current builds up too rapidly, then the amount of current flowing at the instant the short circuit breaks is so great as to cause a violent arc with a great deal of spatter. When the correct rate of change of current is used, the molten puddle receives the right amount of push, and the short circuit breaks into an arc with a minimum of spatter.

The level at which saturation occurs in the added reactance is also important. This permits a smoothing action at low currents during the initiation of a short circuit, but permits the current to build up if the short circuit is of such duration to warrant a higher current for creating an arc. This action is usually required during prolonged short circuits at the time of arc starting.

The effect of this type of arc welding is to permit much lower current and wire-feeding speed on any size wire. The feeding range is increased downward by about 40–50%. For example, 0.035-in. wire under normal operating procedure would have a lower limit of current of about 200 amp, and wire-feed speed of about 250 ipm. With this new method of welding, 0.035-in. wire would be able to perform at 100 amp—160 ipm.

Wider Application for Consumable-electrode Welding

The effect of this development in gas-shielded welding is to permit successful lower-current welding which was impossible before. Since steel welding with CO_2 gas produces a hot arc, this means that a method now exists to permit manual welding at currents much lower than before. These low currents permit the manual welding of $^1/_{16}$-in. sheet steel. In addition, very poor fit-up does not make the process difficult. Gaps which would be intolerable in stick-electrode welding are easily done with CO_2–dip-transfer welding. Figures 4A and 4B illustrate a $^1/_{16}$-in. mild-steel fillet joint made with CO_2 shielding. Note the excellent weld made with a constant-arc-length welding machine—using the dip-transfer technique—as opposed to the poor weld made with a standard drooping (stick-electrode) welding machine (Fig. 4B). Both welds were made under the same optimum conditions of current and voltage.

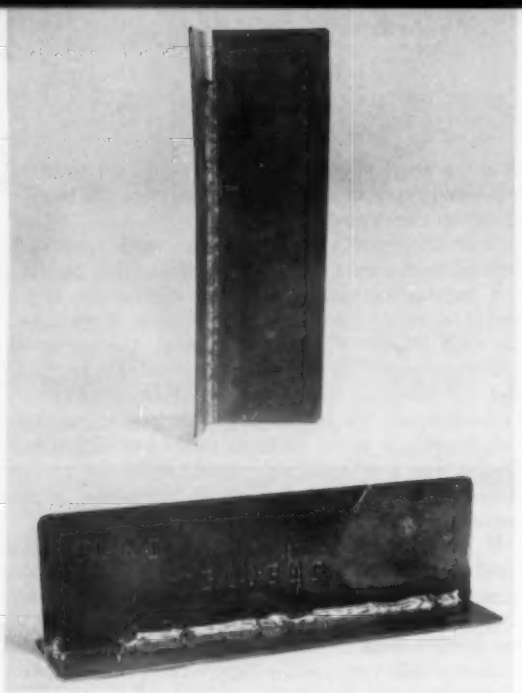


Fig. 4A (top)—Fillet weld in $^1/_{16}$ mild steel, made with weldng machine designed specifically for dip-transfer welding
Fig. 4B (bottom)—Fillet weld in $^1/_{16}$ mild steel, made with standard drooping-characteristic-type welding machine

All diameters of wire electrodes will be able to use lower currents and feed at slower rates and still give less spatter, as a result of this development in power supply characteristic. For practical reasons, however, only the smaller wire sizes will be significant. This is based on the following reasoning.

The object of welding is usually to deposit as much metal as possible in a given period of time. It is generally accepted that there is a practical maximum amount of current which is usable on any given joint, and this is primarily governed by the thickness of the plates to be welded. In gas-shielded consumable-electrode welding, at a given current, the smaller of two electrodes will have the highest deposition rate of molten metal. This means that the applications of dip-transfer welding will be done better by smaller wire than larger wire.

Let us look at this from a practical standpoint. Consider, for example, welding at 300 amp. Although an 0.010-in. diam electrode would melt faster than $^1/_{16}$-in. (0.062) electrode, it would not carry 300 amp. An electrode 0.045-in. diam, however, will carry this current and will deposit more pounds per hour than the $^1/_{16}$-in. electrode. To get a better picture of this, consider the other extreme, Suppose the electrode was 1 in. in diam—it would tend to carry the current like a tungsten electrode and would hardly melt at all. The idea is to always use the smaller of two electrodes, which will permit welding with the required current since it will deposit more metal in pounds per hour.

If the joint design or application demands a very small deposit, or a deeper penetration for the same deposit, then a larger electrode is indicated. This is because, at the same current level, less metal will be melted with the larger electrode than with the smaller.

As indicated by the above examples, dip-transfer welding presents a significant advancement in fabrication techniques. It will increase the scope of the CO_2 gas-shielded welding of steel to manual welding of thin sheet-metal with small wire, rather than permit all electrode sizes to benefit tremendously. If it is found, for example, that a $^1/_{16}$-in. electrode would operate better at a particular lower current setting, then using the dip-transfer technique and the correct power supply, 0.045-in. electrode would probably do the job better and faster.

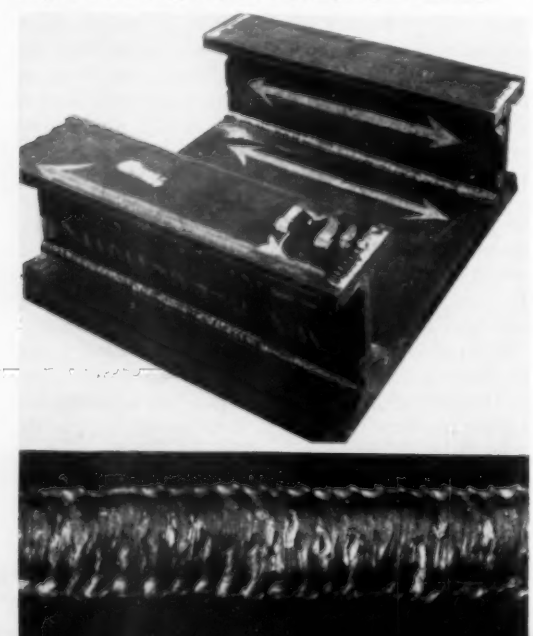
As far as other metals and other gases are concerned, the dip-transfer technique will find use on low currents during short circuiting. This occurs, to some extent, on aluminum, but under normal welding conditions the drops of metal are free-falling and no short circuiting occurs. If no short circuiting takes place, dip-transfer type of welding does not occur. The same thing applies to stainless steel, or the welding of mild steel with argon gas.

Naturally, the presence of CO_2 in the arc must be acceptable metallurgically with the material being welded or else this gas cannot be used. Usually, aluminum cannot be welded with CO_2 additions, but some grades of stainless steel, such as Type 310, may be readily weldable, without loss in weld quality, with the use of CO_2-gas shielding.

Another place where dip transfer will find application is in the out-of-position welding of low-alloy steels. HY-80 is such a steel. Figure 5 shows a weld made in this material with a mixture of 20% CO_2 and 80% argon.

The operation of this new method of welding is

Fig. 5A (top)—Weld in HY-80 alloy steel with 20% CO_2 and 80% argon-gas shielding
Fig. 5B (bottom)—Close-up view of weld bead made on HY-80 alloy steel with 20% CO_2 and 80% argon-gas shielding



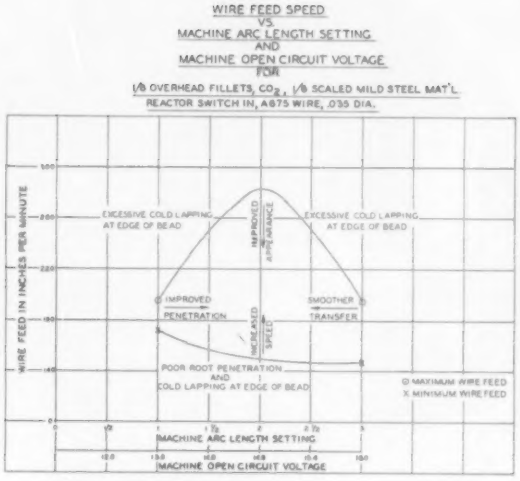

WIRE FEED SPEED
VS.
MACHINE ARC LENGTH SETTING
AND
MACHINE OPEN CIRCUIT VOLTAGE
FOR
1/8 OVERHEAD FILLETS, CO2, 1/8 SCALED MILD STEEL MAT'L
REACTOR SWITCH IN, A675 WIRE, .035 DIA.
WIRE FEED IN INCHES PER MINUTE
EXCESSIVE COLD LAPPING AT EDGE OF BEAD
IMPROVED APPEARANCE
EXCESSIVE COLD LAPPING AT EDGE OF BEAD
IMPROVED PENETRATION
SMOOTHER TRANSFER
INCREASED SPEED
POOR ROOT PENETRATION AND COLD LAPPING AT EDGE OF BEAD
MAXIMUM WIRE FEED
MINIMUM WIRE FEED
MACHINE ARC LENGTH SETTING
MACHINE OPEN CIRCUIT VOLTAGE

Fig. 6A—Operational welding chart for $^1/_8$ in. mild steel

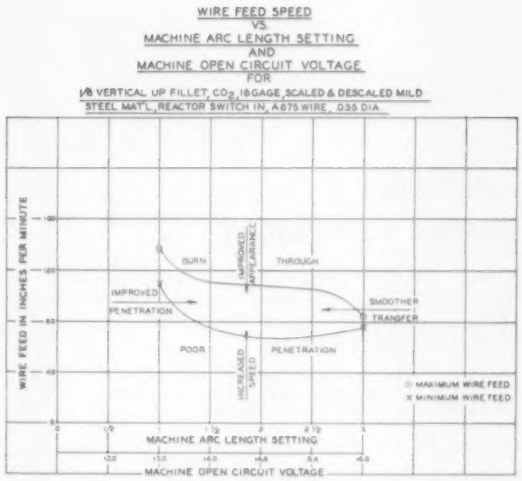


Fig. 6B—Operational welding chart for $^1/_{16}$ in. mild steel

aided by the use of charts similar to those shown in Figs. 6A and 6B. These charts give optimum feed and arc-length settings for best results of appearance, speed and reduced spatter.

Stick-out is the amount of electrode between the arcing point and the contact tube. As this is increased, the operation of dip transfer becomes much more critical. This distance should be not more than fifteen times the electrode diameter. The larger the stick-out, the more the end of the electrode becomes "mushy"; this increases the tendency to form large drops of metal, which are not controllable and produce spatter.

Dip-transfer welding can also be accomplished with transformer-rectifier welding machines, if they are designed to have the proper type of dynamic characteristics. This permits the same good results as with motor-generator welding machines. Figure 7 shows a typical rising-characteristic transformer-rectifier welding machine.

When welding in any position, the diameter of the molten puddle is controlled mostly by the amount of welding current. The larger the current, the larger the puddle. With a given amount of current, as mentioned above, the smaller of two electrodes will melt the largest quantity of metal. Out-of-position, vertically up and overhead welding require considerable skill with conventional methods. However, dip-transfer welding is especially suited for out-of-position welding where nearly all metal is transferred by contact between the electrode and the work. Since the drops of metal do not fall through the arc, they do not become superheated.

The reason that this process is faster than any other known process, including stick-electrode welding, in the vertical and overhead position, is because in out-of-position the amount of current that can be used is controlled by the size of the puddle that can be supported by surface tension. With a given

Fig. 7—Rising-characteristic constant-arc-length transformer-rectifier welding machine

Fig. 8—Fillet weld in $^1/_4$ in. mild steel made in vertical-up position

current, the smaller of two sizes of electrode will deposit the most metal, and with dip-transfer welding, very small 0.035-in. diam electrodes are usually used. This permits much faster welding. A sample of this type of vertical welding is shown in Fig. 8.

Skill requirements for this new type of welding are very low. Both men and women, even with no previous welding experience, make acceptable welds in a matter of minutes. This easy operating characteristic is one of the good features about this new method of welding, making it eagerly accepted by those with little or no experience.

The work done designing a power supply for dip-transfer welding is considered to be very significant. The new power-supply development establishes the fact that the correct dynamic, as well as the correct static, characteristic—rising arc voltage—is essential to produce the ideal welding machine for consumable-electrode welding.

One of the
principal applications of

Extrusions in Tank Fabrication

is their use as main supporting members for vessels subject to internal and external pressure

BY MARTIN J. COEN

Fig. 1—Extrusion with additional stiffening

General

Because of their versatility, extruded shapes find a multitude of uses. This article is intended as an account of their use as the main supporting members in the fabrication of vessels subjected to internal and external pressure.

These extruded shapes have been used in the construction of cryogenic equipment. This type of equipment is a very critical unit consisting of an inner vessel subject to internal pressure and an extremely low temperature, and an outer vessel subject to external pressure and, in some cases, a very high ambient temperature. The annular space between the two vessels is only a few inches, through which these extreme temperatures must be maintained in order to insure proper functioning of the unit.

To insure such proper functioning, these units must stand up under a series of tests that are far more critical than those of most other types of vessels. The inner vessel must, in addition to standard ASME construction and hydrostatic testing, also stand up under pressure and helium leak-detector tests. The outer vessel is also built to ASME specifications but must, in addition, pass probing under vacuum conditions. Both vessels as a unit must show satisfactory results in their ability to maintain a vacuum condition. Under such testing, only the best of welded joints will produce satisfactory results. Both vessels must, of course, pass X-ray inspection.

Trailer tanks for cryogenic use are, for the most part, built with an inner vessel of stainless steel and an outer vessel of carbon steel. All such units operating on public roads must not exceed specified maximum weights when loaded; therefore, if the net weight of the unit can be reduced, the payload can be increased.

To increase payload capacity, it was decided to build units of high-strength aluminum. The first unit fabricated in the conventional method was a complete failure, due to lack of experience in proper fabricating and welding procedures. To simplify fabrication and reduce the cost of labor, the extruded shapes, cross sections of which are shown in Figs. 2 and 3, were designed,* for use in the construction of aluminum trailer tanks of this type. The shapes were extruded according to this design by the aluminum supplier.

These extrusions were first used in the fabrication of tanks capable of carrying approximately 4000 gal

MARTIN J. COEN is associated with Kenmore Associates, consulting engineers.

* Extrusion designed by the author.

Fig. 2—Cross section of extruded shape

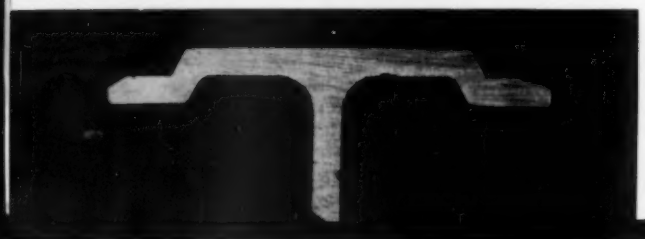


Fig. 3—Cross section of extruded shape

of liquid oxygen, built for and delivered to commercial customers. This same idea was then adapted, by changing size, for use in large portable storage tanks over fifty feet long and approximately nine feet in diameter, built for government projects.

This same method of fabrication, which has proved itself to be not only radically different, but a great deal more efficient and economical than the conventional method of tank fabrication, can be applied, by proper design modification, to any size tank. It can also be used, as proved in these cases, to meet all ASME code requirements.

An examination of the extruded shapes will show, to anyone experienced in welded joint design, a similarity to the well-known toggle type joint. The difference between the toggle joint and that of the extrusion is definitely reflected by the attitude of companies engaged in the business of inspecting and insuring pressure vessels. While the toggle joint is looked upon with disfavor by such companies, these extruded type joints were accepted without argument.

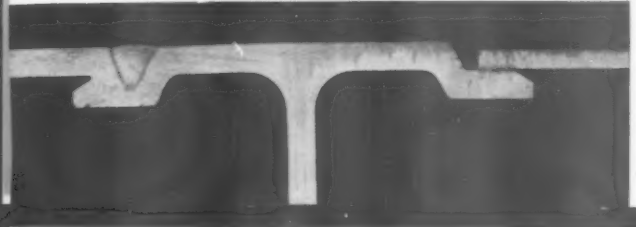
The use of such extrusions, produced of high-tensile aluminum, coupled with automatic inert-gas metal-arc welding, produces two extremely favorable results, reduced weight of unit and reduced cost of manufacture, of benefit to both user and manufacturer.

As stated previously, this method of fabrication is now being used in the construction of large storage tanks, and also for construction of trailerized vehicles for the transportation of liquid gases. In both types of units the lightweight feature is of importance. In the first case, the unit is light enough to be delivered to the installation site by air. If, in the future, relocation of such units are necessary, it can also be accomplished by air transportation. In the second case, that of the trailers, the customer gets extra payload capacity.

The cost of fabrication is reduced, first of all, by reducing the number of parts to be fabricated. Secondly, the method of fitting and fairing courses is such that time required for these operations is considerably less than would be required by the conventional methods. Thirdly, there is no back grinding or chipping required and fourth, the amount of welding is reduced.

The extrusions are designed to incorporate the stiffening members as an integral part of the shell. This will eliminate fitting and welding of stiffening members. The extrusion serves three separate purposes: (*a*) it is a part of the shell; (*b*) it provides backup strips for the welded girth joints; and (*c*) it serves as a stiffener-ring assembly. The thirty-degree bevel is sufficient to eliminate the need for beveling of the mating shell plate. Figure 4 shows one joint made up with $^1/_4$-in. plate and ready for welding, and a welded joint made up with $^3/_8$-in. plate. This represents the construction of an inner shell where the courses are of $^1/_4$-in. material and heads of $^3/_8$-in. material. In addition to saving the time required for edge preparation, the use of such an extrusion saves the time that would be required for handling, shearing, rolling, fitting and welding of stiffener rings and circumferential backup strips. The shape shown in Fig. 2 is used as head rings for the inner and outer vessels of the dewar. For the inner vessel it also serves for stiffener ring and baffle assemblies. The shape shown in Fig. 3 is used for stiffener ring assemblies for the outer vessel of the dewar.

Fig. 4—Joints ready for welding



The size of the extrusion that can be used is governed by the available capacity to roll to circular shapes. When stiffener-ring requirements exceed such capacity, the additional stiffening can be added as shown in Fig. 1; here there are two rolled angles welded to the extrusion shown in Fig. 3. It will be noted in Fig. 3 that the end of each leg is beveled. The purpose is to provide means of welding, when necessary, additional stiffening members without having to do edge preparation. A cross section is shown in Fig. 5. Storage units, generally larger and operating at higher pressures than transport units, will require heavier extruded sections. The heaviest extrusion that has been used in this type of work is approximately 18 lb per linear foot.

Fabricating

The extruded shape is first rolled to the required diameter. The ends of these rings are trimmed, beveled, and welded. When used for outer shell supports, a complete subassembly is made up, consisting of ring, gussets and strap support blocks, as shown in Fig. 6. At this point, such assemblies

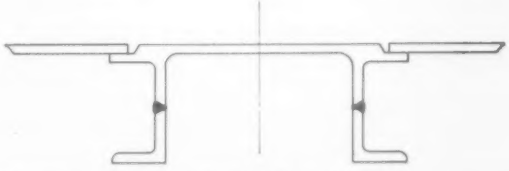


Fig. 5—Cross section with additional stiffening

Fig. 6—Complete subassembly

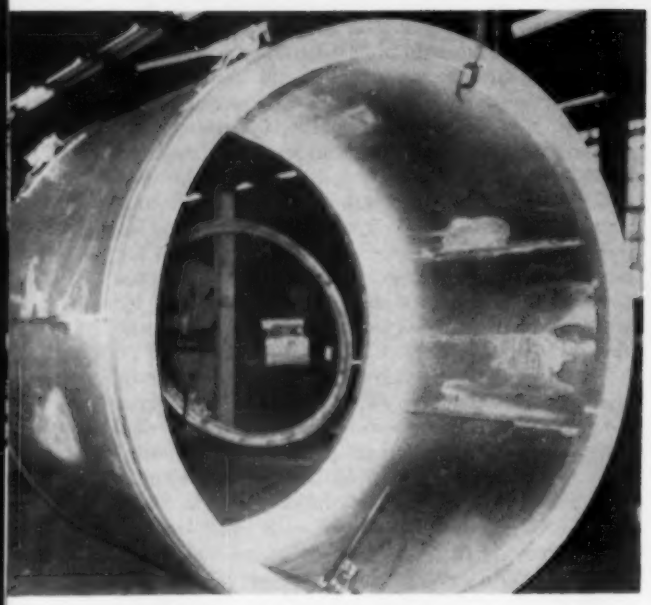


Fig. 7—Sections for final fabrication

Fig. 8—Inside view of outer shell

should be quarter marked so they can be properly matched during fabrication, to be sure the support blocks in the various assemblies line up. Layout for strap access holes are also made at this time.

After fabricating, these subassemblies are then cleaned, as explained later. After cleaning these parts should be processed and welded with the shell plate as quickly as possible. Either of two methods may be used for final fabrication; sections may be made up as shown in Fig. 7, or the job may be a continuous operation. In both cases the operations involved are basically the same and consist of strapping the shell plate to the ring assemblies.

The rolled shell plate is chemically cleaned just prior to this operation. A spacer is used to maintain a gap of $^{5}/_{32}$ to $^{7}/_{32}$ in. at the root of the joint. If the unit is to be made up of individual sections, the procedure would be to place two such completed sections on a set of fit-up rolls and to properly space these sections. A third shell course is fitted between the two sections and strapped in place. After tacking shell plates to the ring assemblies, the straps can be removed. The shell plates must be pulled up tight to that section of the extruded shape that serves as a backup strip for the circumferential joint. This can be accomplished by the use of come-alongs and cable or by heavy metal-strapping equipment. This method of fitting is continued until the entire length of shell is completed.

Backup strips for longitudinal joints are now tacked in place and the shell is ready for welding. It should be noted that, with this type of fitting, no dogging or wedging of the shell plates is necessary. Fairing of the courses is eliminated because the ring assemblies automatically fair the courses. In addition, the labor ordinarily required for rolling, fitting and tacking backstrips for girth joints is eliminated. The time required by this method for tacking and fitting, up to this point, is approximately 50% of that which would be required if the vessel were tacked and fitted in the conventional manner.

All of the welding of longitudinal and girth seams is done with automatic inert-gas metal-arc welding, using 600-amp constant voltage equipment. Heads of outer vessels are not fitted and welded until after dewarizing.

Fig. 8 shows an inside view of an outer shell after welding is complete and straps for supporting the inner vessel are in place. This figure also shows the small amount of tack welding required for this method of fabrication.

Inner vessels are fabricated in the same manner as that described for outer vessels. The extruded shape shown in Fig. 2 can be used without additional stiffening for stiffener ring and baffle assemblies, shown in Fig. 9. Figure 9 shows a complete tank, except for one head, completely fitted and tacked. The next step is to fit and tack the second head in place. When this is done the entire unit will be ready for automatic welding. The unit shown in Fig. 9 is 67 in. in diam. The head will be fitted to the head ring, which is already shown tacked in place to the shell plates. The head ring and the baffle ring are identical in shape; cross sections of both are shown in Fig. 2.

In Figs. 2 and 3, it will be noted that both of the sections which serve as the backup strips are beveled. The purpose of this is for ease in fitting the

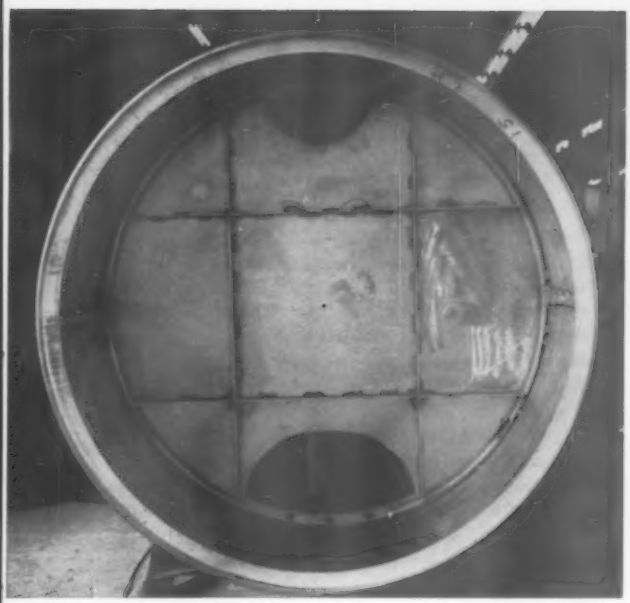


Fig. 9—Ring-and-baffle assembly

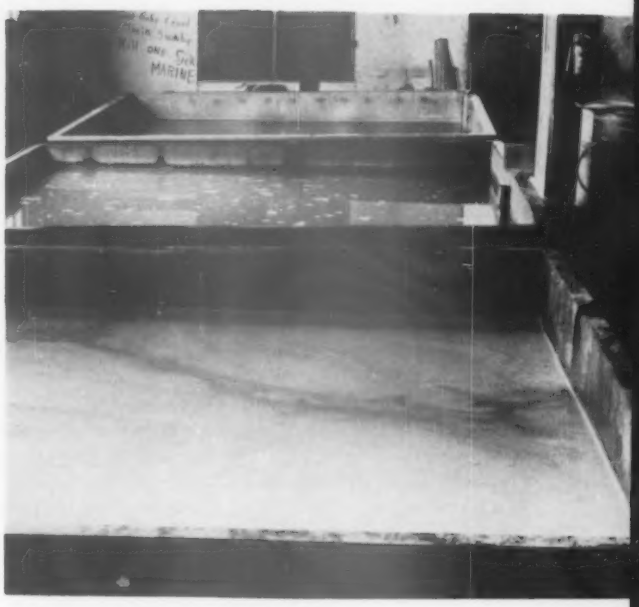


Fig. 10—Three-tank setup for cleaning

heads; in the conventional method, it can consume a considerable amount of time and requires dogging and fairing of the shell to line up with the head. By using extruded shapes, the heads are simply slipped onto the ring and tacked. The ring-and-baffle assembly shown in Fig. 9 was made up as a subassembly before fitting the shell plate.

Cleaning

One of the most important factors in the fabrication of any aluminum is cleanliness. This is particularly true of the 5083 and 5086 alloys. It is even more important when these alloys are to be used for making liquid-gas containers. A liquid-gas container is unique in that its inner vessel is subjected to extremely low temperatures while its outer vessel may be subject to high atmospheric temperatures, all of which means that this type of unit must be exceptionally well constructed. This, in turn, means exceptionally good welding, and cleanliness is a must for this type of welding.

The 5083 and 5086 alloys, as received at the fabricating plant, have an extra-heavy oxidized surface as compared with other aluminum alloys. This oxidized surface must be removed evenly, quickly and without damage to the aluminum. For this reason cleaning methods usually used for other types of aluminum alloys are not completely satisfactory. Mechanical cleaning should not be used on these units; it does not produce a consistently satisfactory job, the aluminum does not remain clean for as long a period as with a good chemical cleaning and, finally, the labor cost is considerably higher. After trying a number of different compounds and methods of cleaning, the desired results were obtained by using a rust stripper solution in large dip tanks. The following four-step procedure is used for all parts that are to be welded. (1) Submerge aluminum in rust-stripper solution (1# per gallon of water) for ten minutes at room temperature. (If tanks are heated, concentration can be reduced.) (2) Remove and submerge in tank of clear, running water or hose down with clear water. (3) Submerge in chromic-acid solution (8 oz. per gal) long enough to remove smut, about five minutes.

The length of time indicated for the above operation is approximate; the actual time that is required depends on the condition of the solution and the surface condition of the metal. Titration materials are made available to shop supervisors for the purpose of checking solution strength periodically.

Figure 10 shows a three-tank setup for this type of cleaning. The tank in the foreground contains the rust-stripper solution; the second contains clear, running water; the third contains the chromic-acid solution. The first two tanks are fabricated of mild steel, while the third, which contains the acidic solution, is made of 304 stainless steel.

In the first step of this operation the alkaline solution removes oil, inks, and other shop soils and at the same time etches the aluminum surface. Following the rinse, Step 3 provides an acidic treatment which removes the heavy smut and provides a uniformly clean surface. In addition, this acidic treatment stabilizes the surface and allows a longer holding time between the cleaning and welding operations.

Shell courses are cleaned after rolling. Figure 11

shows a section prior to cleaning. Figure 12 shows the section after cleaning. Subassemblies are cleaned as a unit just prior to fabricating with the shell courses.

After the ring assemblies and shell plates are tacked together, and just before the welding is started, the girth and longitudinal joints are wire brushed lightly to remove any dust or dirt accumulated during fabrication. For this operation, a stainless steel brush should be used. Hydrocarbons should not be used to remove such accumulated dirt. The results of using such cleaners can be injurious to the welding operator as well as producing porous welds.

Welding

Automatic inert-gas metal-arc welding is used on all girth and longitudinal joints and, wherever possible, on subassemblies. The equipment used is a 600-amp constant-voltage motor-generator welding machine and wire-feed unit. This welding unit is equipped with a beam carriage which allows the unit to travel on an overhead monorail. This method of travel is ideally suited to this type of fabrication, and eliminates the necessity of a costly manipulator that would be required if such a carriage were not available. In addition to reducing original equipment cost, there are no maintenance costs for the monorail, as would be required for the proper up-keep of a manipulator. When welding equipment is suspended at the end of a long manipulator arm, it is subject to a great deal of vibration, with obvious results. With beam carriage and monorail equipment, the welding head is hung directly from the monorail, allowing for a smooth, even motion.

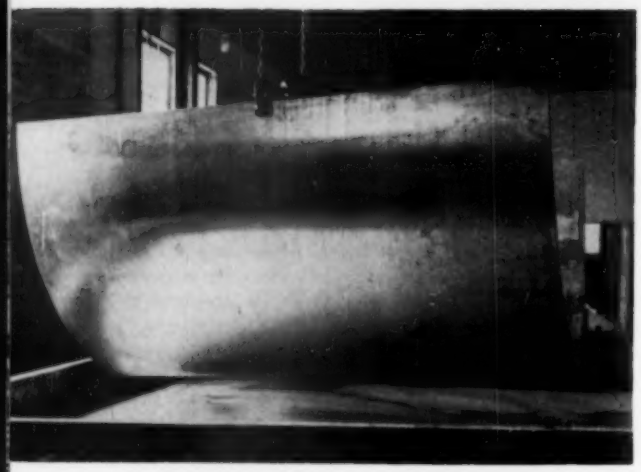


Fig. 11—Section of shell course prior to cleaning

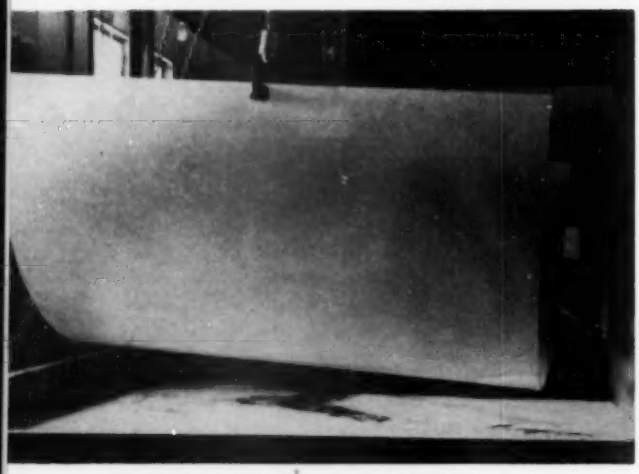


Fig. 12—Section of shell course after cleaning

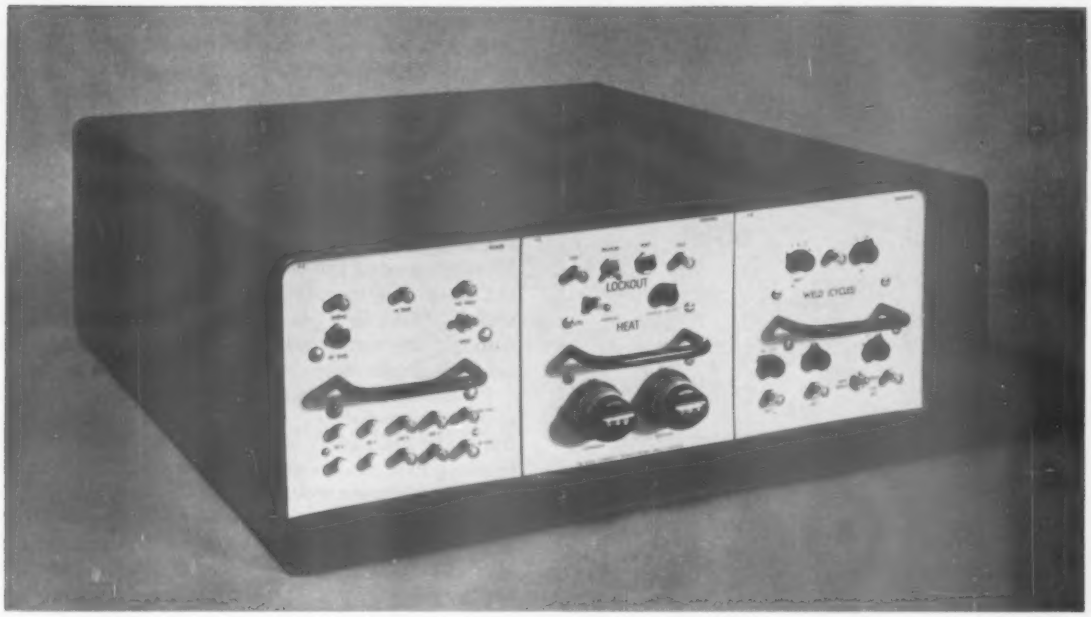
Another feature of this equipment is that controls for current, voltage and speed are grouped on one panel within easy reach of the operator. This type of control allows the operator to start his weld with higher current than he will use for the rest of the weld, in order to insure good penetration at the start. As the weld progresses, the operator can vary the controls to maintain a constant depth of penetration and produce a smooth, uniform weld. This type of control also allows the operator to take care of any minor irregularities in joint fit-up without having to remove his helmet during the welding operation.

The wire used in these operations is $^{3}/_{32}$ in. diam of the 5356 alloy. All wire of this type should be checked before doing any production welding. This can be done by running a few beads, about 15 in. long, from each reel and X-raying. If porosity shows under X-ray, the reel should be rejected. This, of course, is done on material of the same kind and cleaned in the same manner as the production material. Even though the wire proves to be good at this point, it is still necessary to observe precautions to keep it this way. Porosity will show up in the welds if the wire is allowed to accumulate dirt or grease while being used. For this reason, the wire should be covered at all times.

The weld shown in Fig. 4 was made in two passes with 290–300 amp, 25 v, at a speed of 19 ipm. These figures will, of course, vary with different jobs. Where extra-heavy extrusions were used on these projects, 400 amp were required to obtain proper penetration. Best results with the type of joint shown in Fig. 4 are obtained by adjusting the head so the wire is fed at an angle of about 5 deg from the vertical direction of welding and tipped also by the same amount into the straight side of the joint.

The welding unit used on these jobs is equipped with adjustments so that the head can be tipped in two directions at the same time. For longitudinal seams, the adjustment is used for one direction only and the wire is fed in at about 5 deg in the direction of welding.

Use of the extruded shapes and the method of fabrication described, plus automatic inert-gas metal-arc welding, can produce in 1400 hr an aluminum unit that would require 1800–2000 hr by conventional methods of fabrication.



A voltage-constraint control

A New System for **Automatic Feedback Control** of Resistance Spot Welding

compensates for all the common resistance welding problems. The background analysis, design features and performance of the system are presented

BY G. R. ARCHER

"Voltage Constraint" is the name given to a new form of resistance-weld control. Certain features of this system distinguish it from conventional spot-weld controls.

The control uses feedback signals from each weld to set the current. This feedback enables the system to compensate for all the common process variations that would ordinarily have bad effects.

The feedback control can be related analytically to temperature control. Knowing the temperature within a spotweld has always been desirable. Measuring that temperature has been difficult, if not impossible.

The analysis that preceded the building of this control system correctly predicted the abilities and behavior of the system. There is nothing very new in the analysis, but the slant taken is a little different. The high points of the analysis serve to introduce and explain this voltage constraint spot welding control.

G. R. ARCHER is Chief Engineer, Electronic Controls Section, The Budd Co., Philadelphia, Pa.

Paper presented at the AWS National Fall Meeting held in Detroit, Mich., Sept. 28–Oct. 1, 1959.

How Resistance Spot Welds Heat

Resistance heating of two parts to a temperature lower than melting progresses about as shown in Fig. 1. This is a standard case of heating. Analysis is rather simple because the power input alone determines the temperature response.

The temperature response for a spot weld, where melting occurs and a cast structure or "nugget" is formed, is shown in Fig. 2. In heating of this type, the temperature response flattens at the melting temperature, remains there till the nugget forms, then increases again. The interval through which

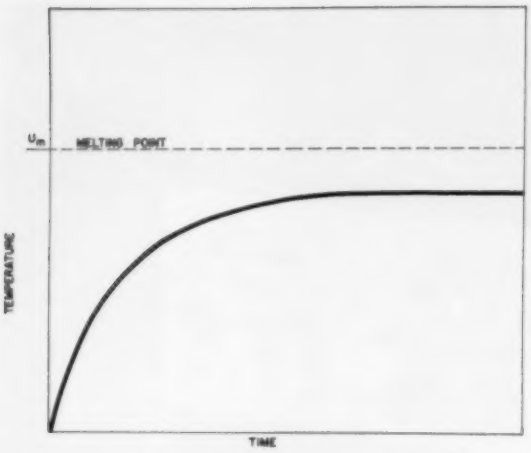


Fig. 1—Heating to slightly less than melting temperature

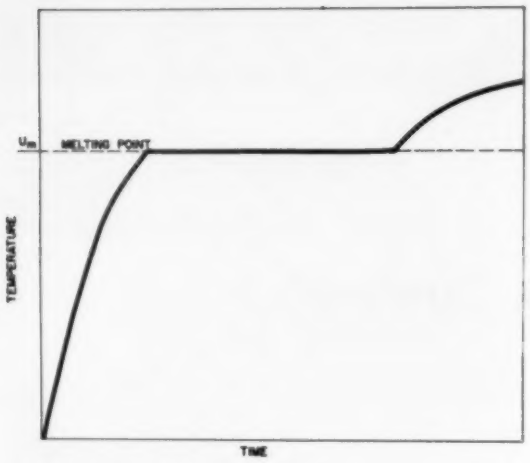


Fig. 2—Heating that involves melting

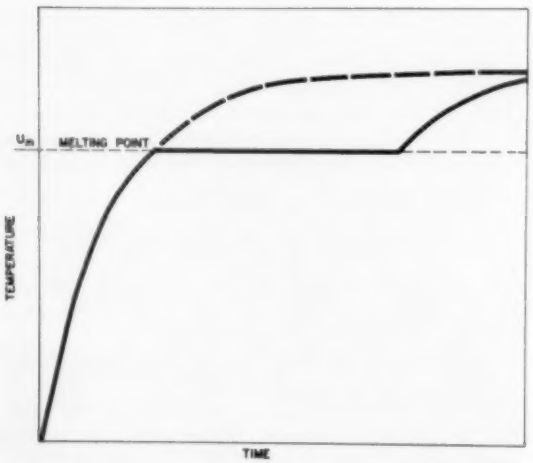


Fig. 3—Melting—actual and supposed

the temperature holds at the melting point is a "stranger." The rest of Fig. 2 is similar to Fig. 1; it represents ordinary heating.

Casting a nugget involves changing the state of the metal from solid to liquid. This change of state requires energy, specifically, the latent heat of fusion. The key word here is "latent"; the energy is hidden. It is difficult to pull out a measurement of this particular energy. During the rest of the heating period it is the *power* that is important. Measuring all of the energy used in a spot weld has not been too useful. We know that 1000 amp. makes a weld in a few cycles. One ampere passed through the same resistance for a hundred years involves more energy but does not make a weld.

Power, then, is required to bring metal to the melting temperature; energy is required to change the state from solid to liquid. This interplay between power and energy complicates the analysis of heating where a weld is formed. Suppose that we ignore for a moment the change of state. In Fig. 3 the dashed line shows a response that ignores the change of state. The response shown in Fig. 2 is repeated as a solid line. It is easier to work with the supposed (dashed) response, because we are dealing only with power. When we have supplied the power required by the supposed temperature response for an adequate period of time, the energy requirements of the latent heat of fusion will be satisfied. This energy does not have to appear in the analysis. This simplification allows us to say that heating to a temperature above the melting point is not so different from heating to a temperature less than the melting point.

In these simplified cases of heating, the highest temperature attained—or supposed—is dependent on heat balance. Balance implies that power input is exactly equal to losses. With this equality, there is no surplus power to cause temperature to increase;

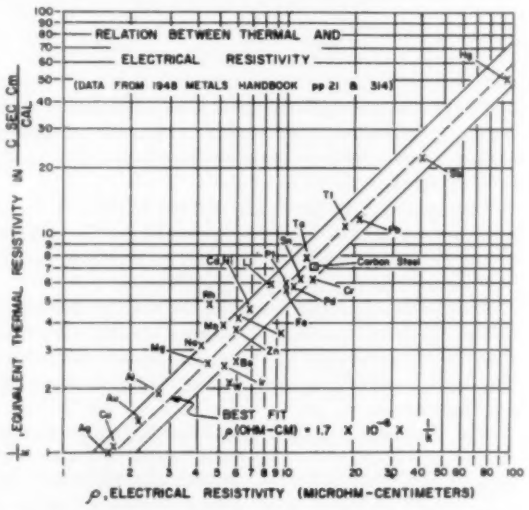

RELATION BETWEEN THERMAL AND
ELECTRICAL RESISTIVITY
(DATA FROM 1948 METALS HANDBOOK pp 21 & 314)
EQUIVALENT THERMAL RESISTIVITY IN — C. SEC. Cm / CAL
BEST FIT
ρ (OHM-CM) = 1.7 X 10⁻⁶ X T/K
ρ, ELECTRICAL RESISTIVITY (MICROHM-CENTIMETERS)
Carbon Steel

Fig. 4—Relation between thermal and electrical resistivity

no lack to cause temperature to decrease. Power is supplied to a resistance spot weld as I^2R_w (current squared times weld resistance). Most of the power leaks out through conduction to the water-cooled electrodes. This conductive loss is expressed as $(U_u - U_a)/rt_w$. The term $(U_u - U_a)$ is the difference between the ultimate temperature and ambient or water temperature. The temperature difference causes heat to flow through the weld's thermal resistance, r_{tw}. Heat balance at a final temperature is expressed as:

$$0.2389\ I^2R_w = \frac{U_u - U_a}{r_{tw}} \qquad (1)$$

where the constant 0.2389 converts electrical watts to an equivalent number of calories per second.

Relating Spot-weld Temperature to Spot-weld Voltage

The expression for heat balance includes both electrical and thermal terms. Making a good spot weld requires knowledge and control of these two forms of power. Part of the success of "voltage-constraint" control can be attributed to the simultaneous treatment of both the electrical and the thermal considerations.

Notice that in the expression for heat balance there are both thermal resistance (the inverse of thermal conductance) and electrical resistance. Voltage-constraint control is based on the relationship between these resistances.

When we consider some familiar materials, we notice that there is a strong similarity between electrical and thermal resistance. Copper, for example, is an excellent conductor of both electricity and heat. Asbestos is a commonly used thermal insulator; it is a very poor conductor of electricity.

Figure 4 is a plot of electrical resistivity (ρ) vs. thermal resistivity ($1/k$, the inverse of thermal conductivity) for 25 metals.*

Note that nearly all the points lie within $\pm 20\%$ of the straight line that *directly relates* the two resistivities. Even uncommon materials like mercury, antimony and sodium are included. On this basis, there is no reason why we should consider electrical and thermal resistivities or resistances separately. We can now express thermal resistance in terms of electrical resistance.

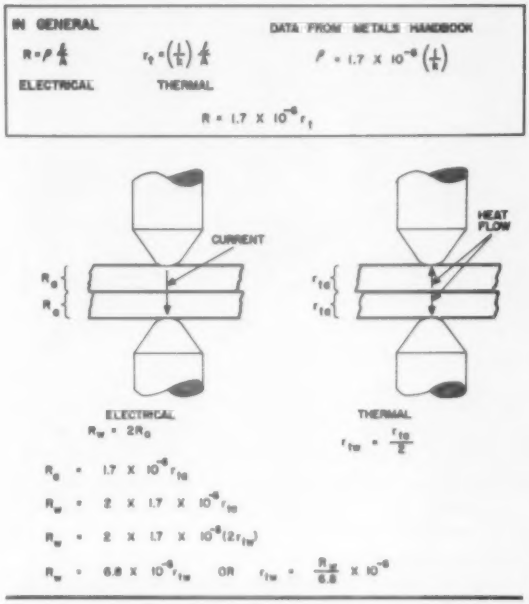
Table 1 shows the steps used to relate electrical and thermal resistances in a spot weld.

General formulas of electrical and thermal resistance both contain the term l/A. This means resistance increases with length and decreases when more area is considered. The resistivities ρ and $1/k$ that make the general formulas different can be related as shown by Fig. 4.

In cases where heat or electricity flow over a certain length and through a certain area $R = 1.7 \times 10^{-6} r_t$.

In a spot-weld, the paths taken by heat and electricity are not the same. The sketches on Table 1 show that the current passes through a weld while

Table 1—Relating Electrical and Thermal Resistances in a Weld



heat flows from the hot center of a weld outward to both electrodes. When the resistance path in the spot-weld is broken into two segments, some relations are evident. Weld electrical resistance is twice the segment R_a since current passes through two lengths. The thermal resistance of the weld, r_{tw}, is one-half the segment resistance because heat can flow through two areas—one to the top electrode, the other to the bottom electrode.

The *segments* of electrical and thermal resistance can be related because, within these segments, heat and electricity flow along identical lengths through identical areas. Some algebra shows that for a weld:

$$r_{tw} = \frac{R_w}{6.8} \times 10^6 \qquad (2)$$

When the expression for heat balance is rewritten using the relation between thermal and electrical resistance, it becomes:

$$0.2389\ I^2R_w = \frac{U_u - U_a}{R_w 10^6/6.8} \qquad (3)$$

or

$$3.5 \times 10^4 I^2R_w^2 = U_u - U_a \qquad (4)$$

By Ohm's law, $E = IR$; therefore, $I^2R_w^2$ must be E^2. Equation 4 then becomes:

$$3.5 \times 10^4\ E^2 = U_u - U_a \qquad (5)$$

Voltage Constraint

Equation 5 is simple. It says that for each ultimate temperature attained by resistively heated metal, a certain voltage must appear across that metal. The only variable that we need to consider,

* These data were taken from the 1948 edition of the *Metals Handbook*.

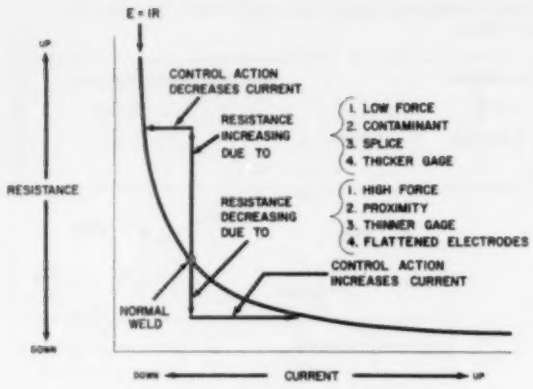


Fig. 5—Voltage-constraint control operation

then, is voltage. It is important to note what is *not included* in the equation. There is no mention of current or resistance. Force is not mentioned. Thickness is not mentioned. Even the material is not considered. The number of parts in the pileup, surface finish, shunting, electrode shape—none of these are considered.

This principle started the evolution of a control system that would constrain the voltage across a spot weld to a preset value. When that voltage produced the related temperature at heat balance, the possibility existed that things not considered in eq 5 would be taken care of automatically.

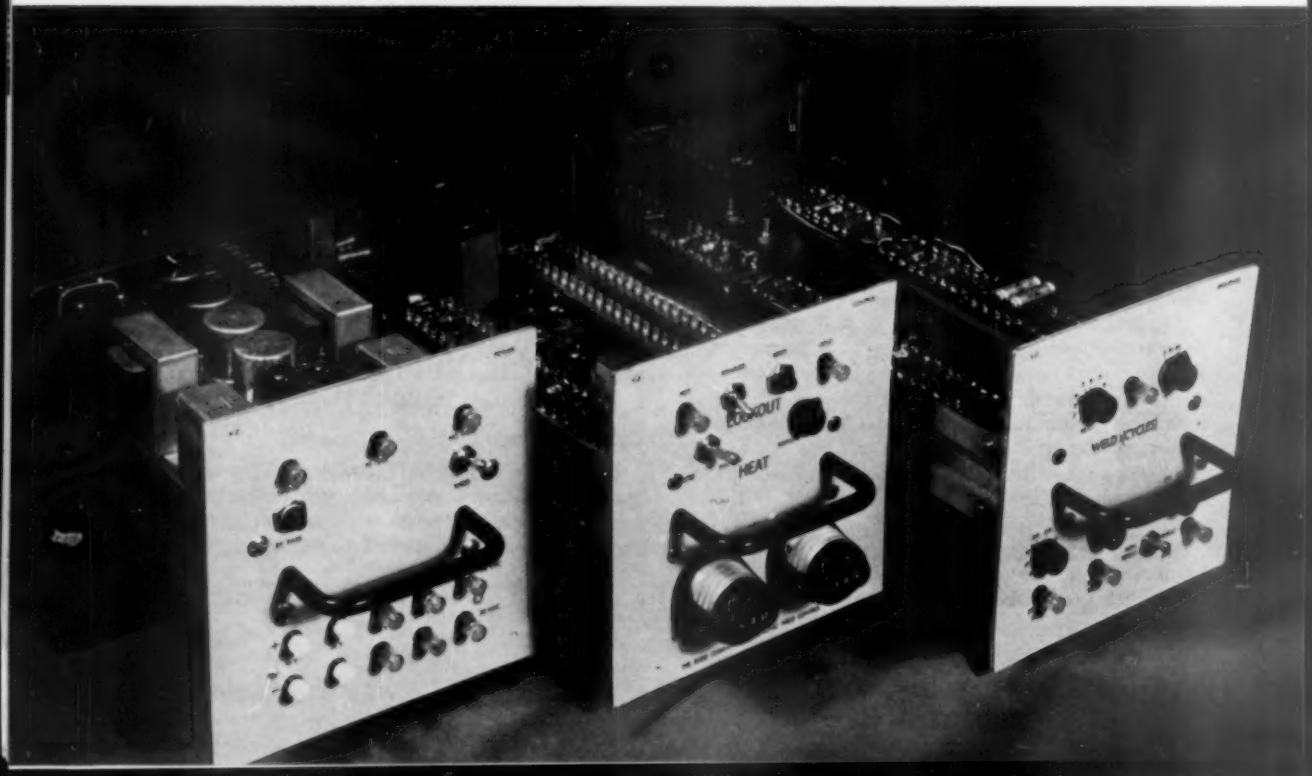
In practice, the system would be as simple as its analytical basis. A voltage that is related to the desired final temperature (the dashed line in Fig. 3) is determined. Then that voltage is used as a command by the control. The voltage across the weld, measured at the electrodes, must equal the command voltage. When the electrode voltage is lower than the command, the control must raise the current. When the electrode voltage is higher than the command, the control must lower the current.

Figure 5 shows a plot of one voltage on scales of current and resistance. If one or more of the common process variations occur, the weld's resistance changes. Unless the current to the weld is changed, the voltage will vary with resistance. The control however watches for high or low voltages and corrects the current to constrain the voltage to be equal to the command. In this way, the control compensates for any variable in the process that affects resistance.

Designing the Controls

In order to put voltage constraint control into practice, four years have been spent in evolving the controls shown in Fig. 6 through 9. These controls function with an externally connected set of ignitrons fired by thyratrons. The sequencing circuits in these controls are similar to those in standard weld controls. Heat control is performed by phase-shift circuitry, but the heat setting is no longer a manual input; it is an automatic input. To derive the automatic heat signal, an automatic control system has been added to the standard weld-heat control. In order for the automatic control system to function, feedback information as to the voltage across the weld must be processed by appropriate input circuits. Several practical objections ruled out making voltage-constraint automatic control an accessory for standard controls. True reliability

Fig. 6—Voltage-constraint control showing power, control and sequence modulus partially withdrawn



required that the system be an integrated whole. Ease of use and maintenance required that the number of packages be minimized. Variations in standard control circuitry would cause difficulty in matching automatic control to different standard controls.

Because of this start-from-scratch approach, the comprehensive design of the control features the most modern circuits possible. The circuitry present in these automatic controls is similar to that used in radar and both digital and analog computers. The integrated systems have fulfilled expectations.

The addition of automatic control to standard control has admittedly increased the complexity. To achieve reliability in spite of complexity has been the object of our four years of design. Maintenance might be expected to be more difficult for these circuits than for standard weld controls. However, modular design has been incorporated in these controls to permit servicing by function rather than by component.

Automatic Heat Control

In determining current level automatically, voltage-constraint control raises the current from the minimum possible level to the level established by feedback of the proper weld voltage. The control detects any error between the desired weld voltage and the actual weld voltage and produces a correction in current. As long as there is any error, a continually increasing correction is made in order to drive the error to exactly zero. The control, then, guarantees that the voltage across the weld is forced to equal exactly what is required.

In raising the heat from the lowest possible level at the start of each weld, the control prevents high inrush currents from occurring in hypersil weld transformers and also provides feedback information at the lowest possible heat level. Information at this low heat level often can prevent expulsion. In cases where weld resistance is very high, even small values of current cause high heating that could be damaging.

The control includes lockout circuits that detect extreme process variations, shut down the control, and draw the operator's attention to these variations. The lockout circuits are linked to the range of current available to the control. The control functions by choosing a current level appropriate for each weld. If the current required by the control exceeds the available capacity of the weld transformer, the control locks out and indicates with a lamp that a weld made under these conditions would be "cold." In cases where the control requires less current than can be delivered reliably, a lockout occurs, and an indicator lamp shows that a weld made under these circumstances would be too "hot." Both the force and heat functions are inoperative when lockout occurs. The nature of a lockout, either "hot" or "cold," serves as a first step in isolating problems in the welding process.

Two to three half-cycles are ordinarily required for the control to stabilize at the particular current level required by an individual weld. This may cause a one- or two-cycle increase in the over-all weld heat interval compared to the normally used schedule. The speed of voltage constraint control action is such that correction to the heat can be made every half-cycle.

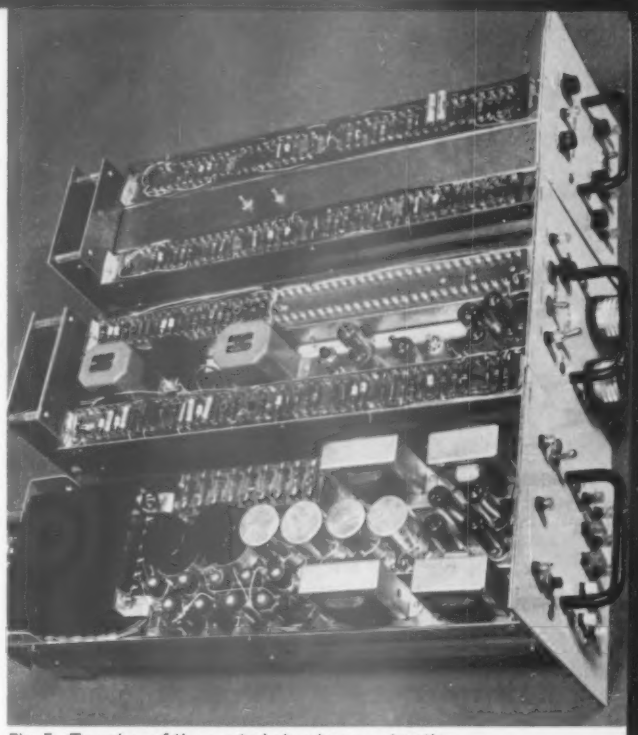


Fig. 7—Top view of the control showing construction

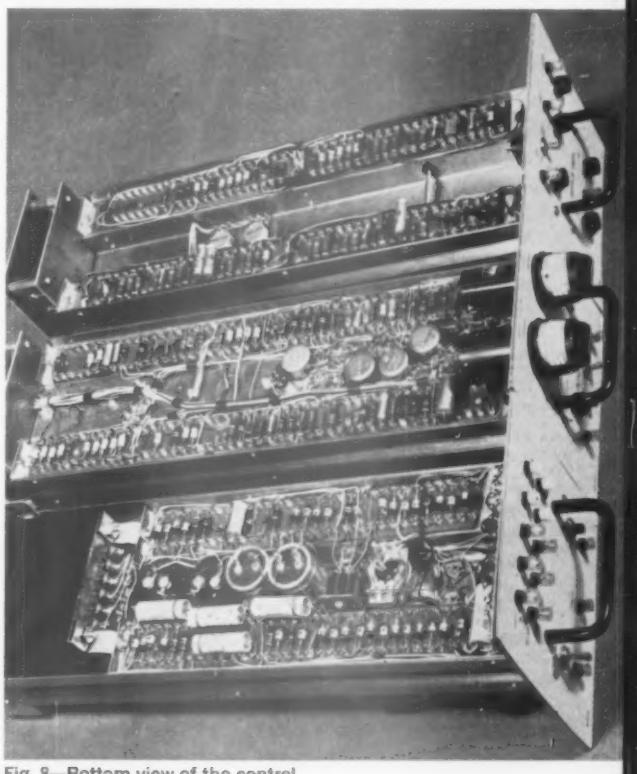


Fig. 8—Bottom view of the control

The controls shown in Fig. 6 through 9 are for single phase, 60 cycles per second operation. There appears to be no reason why other types of power output could not be used in future designs.

Using the Control

In eq. 5 of the analysis, a very distinct mathematical relationship has been made between the voltage across a weld and the final temperature that will be attained within that weld. The constant 3.5×10^4 used in this relationship is valid for d-c or rms heating. To use ordinary weld voltage in eq. 5 we would need its rms value. Establishing a relationship between peak voltage and rms voltage at the various phase shifts used in welding is not convenient. Fortunately it is not necessary, because we are interested in the relationship of eq. 5 and not a specific mathematical constant.

The voltage required at the weld for use with voltage-constraint control is ordinarily determined by experiment. When a weld is made by standard techniques, the voltage appearing across that weld can be observed and recorded. If successive welds are made with that same voltage, our analysis indicates that those welds will attain the same temperature. Destructive testing of a sample weld, just as is common practice now, serves as the basis for the establishment of the desired voltage.

An additional consideration with voltage-constraint welding is the response of the automatic control system.

Voltage-constraint controls include response adjustments not found on standard weld controls. The magnitude of correction made by the control for a given error determines the speed with which it will reduce the error to zero. As was mentioned, the current rises from a minimum level under voltage-constraint control and settles at the level required by the individual weld. If corrections made by the control were too abrupt, the control could act in a "nervous" fashion: overshooting, bouncing and finally attaining the required level. The overshoots could result in the application of excessive current to a spot weld with resultant expulsion. If the corrections made by the automatic control were too small, an extremely long time would be required for the control to establish the necessary current level. Proper setting of the response control provides fast settling with minimum overshoot. It should also be mentioned that some form of instrumentation, usually an oscilloscope, is required in establishing correct response for a schedule. Once that schedule has been established and the response is acceptable, there is no continuing need for instrumentation during a production run.

Results

The results obtained so far with voltage-constraint control have in all respects borne out the expectations of the analysis. We will now consider each of the process variations that normally affect welding.

Line-voltage variations that ordinarily produce variations in transformer secondary voltage, and therefore weld voltage, are immediately sensed by voltage-constraint control and produce no problems in weld strength.

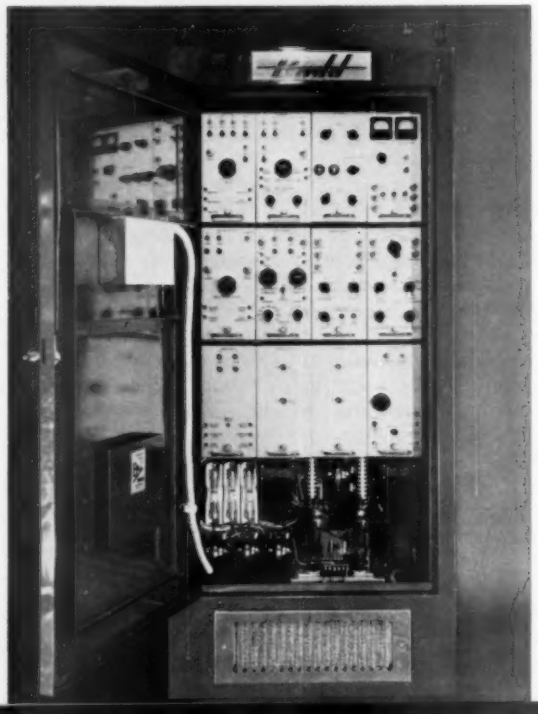
Force variations ordinarily cause serious problems in resistance spot welding. Figure 10 shows how voltage-constraint control compares with conventional control when force varies. Higher forces present a larger area and make possible a larger, stronger weld nugget. Under voltage-constraint control stronger weld nuggets are made. Using conventional controls, however, the preset heat is distributed through the larger area and creates a smaller weld. In exploiting the potential for a larger weld, voltage-constraint control reverses an undesirable effect of conventional controls.

Electrode wear, which similarly presents a larger area for a possible weld, commonly causes decreasing strength with conventional controls. With voltage-constraint control, the wear of the electrodes is sensed by continual monitoring of the voltage; the current is increased as the electrodes wear to produce progressively larger welds.

Surface-finish variations are sensed by voltage-constraint control and cause proper current correction. Contaminants or extreme surface variations are detected immediately by voltage-constraint control and, where they are severe, lockout occurs. In some cases instrumentation has shown that the heat signal under automatic control decreases rapidly, then abruptly turns and increases to a normal level. It has been inferred from this that the contaminant burned away under low heat. Then, during the weld, the control sensed the change and went on to make a good weld.

Shunting effects, whereby successive welds have decreased strengths depending upon how much cur-

Fig. 9—A comprehensive control that combines voltage-constraint control with the resistance-drop control



rent is shunted to previous welds, are dealt with in voltage-constraint controls. Each weld is treated as a separate entity. When conventional controls are set for seam-weld schedules, the heat setting must be developed to overcome shunting part way down the row. This often causes severe burning on the first weld where no shunting is present. Voltage-constraint controls eliminate this difficulty since, again, each weld is controlled independently.

Thickness variation can be compensated for by using voltage-constraint control. In foil gages of 301 stainless steel, a range of 0.0025 in. to 0.014 in. in two-sheet pile-ups has been welded with one machine setting.

From Fig. 5 it will be noticed that the corrective action of the control is to increase current when the thickness of the material decreases and to decrease current when the thickness of the material increases. This is opposite to common practice where heavier gages require more current. Common practice also includes more force and larger electrodes for heavier gages. Where adequate time is available for the control, it has been shown that the action of the control is correct for a wide range of gages without adjustment of other variables. This was shown most practically in our shop when operators who had been welding 0.005 in. 301 stainless changed to 0.003-in. 301 stainless steel. They were perplexed to find that the heat settings on standard weld controls had to be increased to assure fusion. A reduction in gage allows the heat to leak out more quickly; therefore, more heat is required to achieve an equivalent temperature.

Variations in pile-up are also possible for a single schedule controlled by voltage constraint. Tests made with 0.005-in. 301 stainless steel show that two, three or four thicknesses can be accommodated by a single schedule.

While voltage-constraint control compensates for all the common welding variations, *proper* compensation is a matter of judgment. The control compensates to meet a specific analytical requirement of voltage constraint. To some people the degree of compensation may appear not enough; to others, too much. On this basis "bad" welding can result. The fact that compensation is exerted does not mean that the control aims for consistent welds. The control, in fact, aims for the best weld that can be made in any given situation. In some cases the best weld that can be made is larger than standard. In other cases it is smaller. No one wants smaller welds. If, to avoid expulsion, a smaller weld is required by the control, the only apology is that where possible larger welds will be made.

Voltage-constraint control by itself uses a time interval set by standard sequencing. The setting of weld heat time is a matter of judgment, just as it is with conventional control. Insufficient heat-time settings can deny the control time enough to do a complete job. In thin gages, the setting of weld heat time has been found to be less critical.

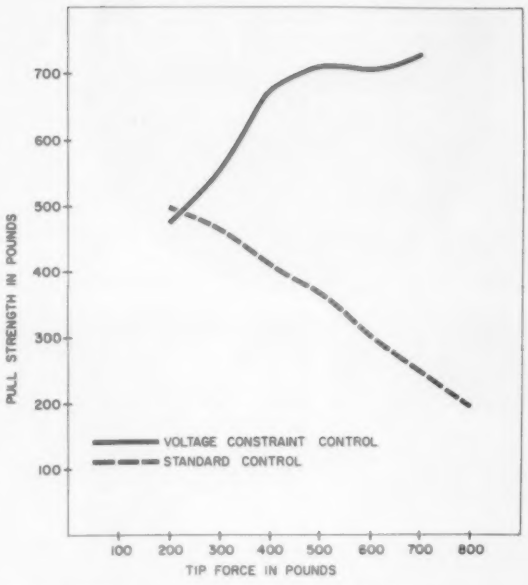


Fig. 10—Effects on pull strengths of 0.020-in. 301 stainless-steel welds with voltage-constraint control and with conventional control

When very heavy gages are welded, common welding practice is to use a heat signal indicative of a final balance temperature far in excess of melting. This means that the temperature rises very rapidly with time. Under some circumstances, process variations occur that require more time for the temperature to rise to the same point (increased gage is one). Since voltage-constraint control operates on a fixed manually set time, less time is available for the growth of the proper weld nugget. Thus the interaction of the thermodynamics of the metal and of the control may cause incomplete compensation.*

Conclusions

A different slant on the analysis of how resistance spot welds are made has indicated a new form of control for those spot welds. Since the analysis was basic, many hypothetical expectations were formed. All of those expectations have been met in voltage-constraint controls. This form of control system is not presented as a panacea. The control can help us to understand spot welding and to make spot welds with better reliability.

Acknowledgment

The author wishes to acknowledge the advantages he received at The Budd Co. while this work was in progress. The guidance of M. Watter and H. D. VanSciver, the association with J. J. MacKinney and many others and the editorial assistance of L. Eisner are greatly appreciated.

* These problems with fixed weld heat time do not apply when voltage constraint is used in combination with resistance drop control reported by VanSciver, in "Spotweld Monitoring by Resistance Change," April 1952 AIEE 3rd Conf., Electric Welding, Detroit

Practical Welder and Designer

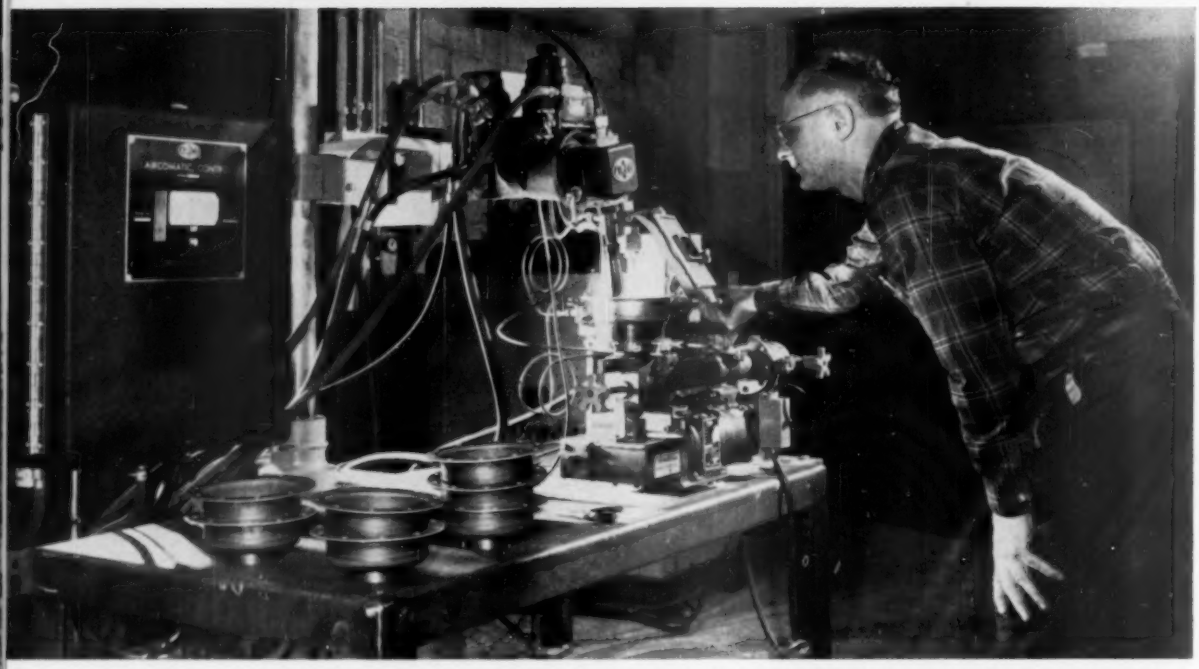


Fig. 1—Inner head of diaphragm-housing assembly of a control actuator is welded with the gas-shielded metal-arc process

Gas-Shielded Metal-Arc Welding Used in Fabricating Intricate Processing Controls

BY GLENN HARTWICK AND GLENN WARREN

Taylor Instrument Cos., Rochester, N. Y., concentrates the bulk of its production in the manufacture of control instruments for use in process industries to indicate, record and control the flow, force, humidity, liquid level, temperature and pressure of steam, gases and liquids.

These instruments are integral parts of the continuous processing of such varied products as chemicals, petroleum, textiles, foods, milk, plastics, synthetic rubber, photographic film and paper.

In processing all of these products, precision control is a must, and instruments designed for the job must be engineered to meet the most rigid performance requirements.

Recently, in redesigning a control-valve actuator, Taylor switched from stick-electrode arc welding to the gas-shielded metal-arc welding process for

GLENN HARTWICK is an Engineer, Engineering Service Organization, Air Reduction Sales Co., Buffalo, N. Y., and GLENN WARREN is Welding Engineer, Taylor Instrument Cos., Rochester, N. Y.

Weld anywhere with P&H portable welders!

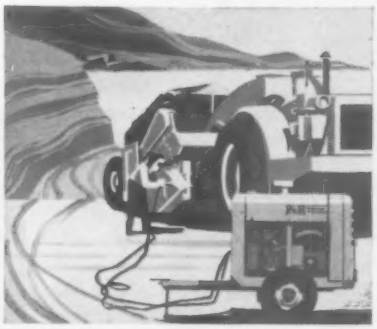
5 engine-driven models enable you to match your needs for construction, pipeline, maintenance, and repair welding in the 25- to 500-amp range

If you use portable welders, you haven't looked at the field until you've seen the new, broad P&H line. Five different models give you a wide choice of sizes to meet your needs and your pocketbook. Easy, precise voltage control and superior current and arc stability enable operators to lay down sounder, cleaner welds faster — prevent burn-through and popouts. The results: fewer rewelds and no costly call-backs.

The rugged, compact P&H welders are built to withstand the heavy use and rough handling on field jobs. They need less care — and they are easier to service. Powerful engines deliver power to spare — with gas-miser economy. A dependable idling control automatically slows the engine down to idling speed when not welding — saves gas and oil, cuts wear.

P&H engine-driven welders come skid- or wheel-mounted — with manual or 6-volt electric starting. For information, write Dept. 308C, Harnischfeger Corp., Milwaukee 46, Wis.

P&H HARNISCHFEGER
WELDERS • ELECTRODES • POSITIONERS



HERE ARE THE FIVE P&H SIZES!

WN-180
Handy, low-cost DC welder for shop and field work in the 25- to 200-amp range.

WNG-200
Compact, light-weight portable for heavy-duty DC welding ranging from 40 to 250 amps.

WNG-300
This rugged middleweight answers your need for trouble-free welding in the 60- to 375-amp class.

WNG-400
Here's cost-cutting DC weld power for the big jobs requiring 80 to 500 amps.

WND-303
This is a diesel-powered newcomer to the P&H line. Unit has a welding range of 60 to 375 amps.

Fig. 2—Closeup of gas-shielded metal-arc welding of inner head of diaphragm-housing assembly of a control actuator

Fig. 3—Closeup of inner head of diaphragm-housing assembly (left) and completed control-valve actuator (right)

fabricating the inner heads of diaphragm housing assemblies (see Figs. 1 through 4).

When using manual stick-electrode arc welding for this work, the company encountered distortion and the parts had to be cleaned by a shot-blast technique in order to remove slag—a time consuming operation. With the new method of welding, savings in time alone were enough to justify the change. Taylor can now weld this assembly in one-tenth of the time anticipated by the previous method, with the added advantages that there is now no distortion and the postcleaning is unnecessary.

To do the job, a gas-shielded metal-arc machine welding head was mounted on a welding positioner designed and constructed by Taylor engineers (Fig. 2). Although a relatively simple construction, the fixture enables an operator to accomplish welding in all positions automatically. A 300-amp d-c arc-welding machine provided the power, and argon plus 2% oxygen was used as a shielding gas.

Fig. 4—Various sizes of diaphragm-housing assemblies

Cool Air and Ice . . . Thanks to a 6000°F Flame

Ice cubes in summer, frozen food in the tropics and comfortable driving even through Death Valley heat . . . these are the things made possible by modern refrigeration equipment. Tenney Engineering, Inc., Baltimore, Md., is one firm that builds these units with the aid of the oxyacetylene flame.

In this modern plant, 25 welding torches in the hands of experienced operators help speed production on dozens of models—ranging from new dwarf-size automobile air-conditioners to giant refrigerator components capable of cooling frozen food storage rooms to subzero temperatures (Fig. 1).

Each model contains tin-plated copper coils—key to the cooling process—surrounded by aluminum fins. A series of straight tubes are joined by shaped tubes which are brazed in place to form this continuous coil for the cooling gas, Freon.

Based on a story by the Linde Co., New York, N. Y.

The Production Line

The straight tubes are first mechanically inserted in the aluminum fins to form a "header." An operator then positions the shaped tubes in the header with the aid of a rubber mallet (Fig. 2). This "coil-fin" section is now rigged so that nitrogen passes through the tubes during the brazing operation. Nitrogen provides an inert atmosphere inside the circuit to guarantee clean scale-free refrigerant passages (Figs. 3 and 4).

Working skillfully with a welding torch, an operator plays the flame on the header connection with a brushing motion. After the solder melts on contact with the hot tube, he begins touching solder to the opening around the joint.

Several years ago, these connections were soft soldered. However, to provide a more durable, pressure-tight joint, this work is now done with brazing.

Soldering means joining two metals at temperatures lower than the melting point of the base metals, say 700° F. The brazing operation is similar to soldering, but temperatures much closer to the melting point of the base metals are used—in the 1200 to 1300° F range.

While working on the connections, if the joint gets too hot, the solder will not spread properly. Severe overheating also causes the solder to seep clear through the joint and run away without sealing the connection.

When a line of solder shows around the end of the fitting, sufficient solder has entered the joint. The operator then reheats the entire area for an instant and wipes away excess solder from around the edge of the joint. The result is a pressure-tight fitting.

Testing Results

When all connections on the "fin-coil" have been

Fig. 1—This large unit is capable of cooling a 900 sq ft storage room to subzero temperatures

Fig. 3—Here brazing is done on coil that will be used in a long refrigerator display case

Fig. 2—Operator positions shaped tubes in header with a rubber mallet. This forms cooling coil

Fig. 4—Nitrogen is piped through cooling circuit during brazing to keep the tube inside scale free

Fig. 5—The operator here is testing a completed "fin-coil" section for tiny leaks in a water bath

Fig. 6—After testing components, cooling units are assembled with the aid of an oxyacetylene torch

braze welded, the part is passed on to the testing stage. Here, an operator plugs one end of the circuit in the coil, screws a tube from a CO_2 cylinder into the other end, and allows pressure to build up in the coils. He then places the entire finished section in a water bath and watches for telltale bubbles that would indicate faulty connections. If no bubbles develop, that section is "okayed" and sent to the assembly station (Fig. 5).

At this point, the coil component is coupled with other machinery and the part is ready for shipment (Fig. 6).

Spray Hard Surfacing Increases Service Life of Fans 20 Times

BY J. E. LOONEY AND S. L. NEWCOM

Spray hard surfacing proved to be the economical method of depositing a thin layer—0.045 in.—of an abrasion resistant nickel-base alloy on this blower fan. Powder recovery approached 95 percent.

Blower fans, spray hard surfaced with a nickel-base alloy powder for protection against erosion, are lasting 20 times longer than fans protected with other materials. The fans, two feet in diameter, are an integral part of a conveying system which moves 30 to 40 tons of grain every 24 hr in a feed-mill operation. Fans protected with a thin layer of the spray powder have stayed in continuous service for 14 months. Normal service life had been 21 days.

Welding Engineers, Marshall, Tex., spray hard surfaces blower fans for companies producing animal feed. The fans, fabricated from a heat-treated steel, are subject to severe erosion from abrasive particles of chopped alfalfa, soy beans and corn. This material is moved to a storage bin by the blower system after being pulverized in a hammer mill.

This alloy powder contains about 75% nickel, 17% chromium and slight percentages of iron and boron. Carbon is held to 0.95%.

The abrasion-resistant deposit is applied to a depth of 0.050-in. with spray hard-surfacing equipment in two passes. A standard oxyacetylene torch is used to fuse the deposit. The end result is a hard, sound, well-bonded deposit, about 0.045 in. thick. Average hardness is Rockwell C 61. Powder recovery, an important factor which contributes to the economy of the operation, approaches 95%. The fused deposit requires neither machining nor grinding.

J. E. LOONEY is associated with Welding Engineers, Marshall, Tex. and S. L. NEWCOM is associated with Haynes Stellite Co., Tulsa, Okla.

This 70-foot towboat, and two 120-foot boats, were constructed in stainless steel from the main deck down, for service at U. S. Steel Corporation Clairton Works, Pittsburgh.

Some of the 20 Vickers Controlarc welders in service at St. Louis Shipbuilding and Steel Co.

"Sewing a seam" in stainless steel with the VICKERS® *Controlarc DC Welder*

Vickers Controlarc DC Welders played an important part in an unusual project by St. Louis Shipbuilding and Steel Company: the construction of the first inland waterway towboats with stainless steel hulls. The three boats were built for service on the Ohio and Monongahela Rivers at U. S. Steel Corporation's Clairton Works, Pittsburgh.

A big feature of the Controlarcs' performance on this job was elimination of stub loss on stainless steel electrodes by *automatic* maintenance of a constant current setting from arc strike to end of pass. With a ton and a half of costly electrodes used on the 10,500 feet of welding, dollar savings were appreciable.

Suitability of the Controlarc for Arcair gauging and cutting was another reason for the choice of this machine.

For better performance on *any* welding job, the Vickers Controlarc magnetic amplifier-rectifier DC Welder provides automatic control of *current* and *type* of arc adaptable to changes in welding conditions. For complete information on this unusual welding machine, write today for Bulletins EPD 7116-1.

expensive stub loss eliminated on stainless steel welding job

VICKERS INCORPORATED
DIVISION OF SPERRY RAND CORPORATION
ELECTRIC PRODUCTS DIVISION
1853 LOCUST STREET • SAINT LOUIS 3, MISSOURI

For details, circle No. 9 on Reader Information Card

DON'T SPEND MONEY... MAKE MONEY

For details, circle No. 18 on Reader Information Card

INVESTIGATE SYSTEMS... NOT MACHINES

Today improvements and refinements in oxygen cutting techniques are making possible important savings in steel mills, shipyards, and metal fabricating plants.

Automated systems—not just machines—are providing these impressive economies.

MESSER CAN INCREASE YOUR PROFITS

Long a leader in developing completely engineered cutting operation systems, Messer can show you how cybernetics in oxygen cutting can boost your profits. The design of Messer cutting systems offers great shop flexibility. It permits wide use of automation—takes advantage of the distinctive construction of Messer machines to set new standards of accuracy in precision workmanship.

THE REVOLUTION IS HERE!

Yes, machines that make the revolution in oxygen cutting are already here. Let Messer work with you to make sure you get the maximum savings and benefits from your own cutting operation. If you use—or could use—oxygen cutting, it will pay you to check now on what Messer can offer you. Write for full information. No obligation, of course. Messer Cutting Machines, Inc., Chrysler Building, 405 Lexington Avenue, New York 17, N.Y.

MESSER CUTTING MACHINES

WELDING ENGINEERING · Messer · SINCE 1898

PRECISION CUTTING MACHINES . . . OXYGEN, NITROGEN, ARGON PLANTS

For details, circle No. 10 on Reader Information Card

Society News

Group Insurance Program for AWS Members Approved by Board of Directors

During the past year, a Board of Directors committee headed by Treasurer H. E. Rockefeller, with Vice-president R. D. Thomas, Jr., Director J. N. Alcock and Membership Chairman T. L. Dempsey as members, has studied various group insurance plans to be administered by others, without expense or income to the SOCIETY which would make accident and health insurance available to members and their dependents on a voluntary basis at attractive group rates.

Your board of directors at their meeting in Chicago on April 9, 1959, considered recommendations of this committee and approved the program outlined in the following paragraphs.

This group insurance program contains three basic plans:

1. The Loss of Time Plan. With benefits for loss of time due to accident or sickness, and accidental death or dismemberment, for AWS members only.

2. The Major Hospital-Nurse-Surgical Expense Plan. With benefits for hospital room and board, miscellaneous hospital expenses, nurse expense while in a hospital and after hospital confinement and surgery. This plan will be offered with the option of either no deductible or $500 deductible coverage. It will be available to members and their spouses and children.

3. The Senior Hospital-Nurse-Surgical Plan. With more limited benefits for hospital room and board, miscellaneous hospital expense, nurse expense while in a hospital and surgery. This plan is designed primarily for members of the SOCIETY over 70 and their spouses.

The key personnel of the administrator of the program have been successfully administering a similar program for the American Society of Civil Engineers for the past ten years, and a program for the American Society of Mechanical Engineers since June 1958. They also have been appointed to administer a program for the American Society for Quality Control and the American Society for Testing Materials.

They assure us that our members will at no time be approached through personal solicitation. Members will soon receive a mailing containing applications and full details of the program.

The program will be underwritten by the Continental Casualty Company of Chicago, Illinois.

There will be a charter enrollment period of six months from the date of the first mailing. During that time, if 40% of the members enrolled in any section (or of the entire AWS membership) apply for coverage, all applications received will be accepted regardless of the physical condition of the member (though members over 60 and impaired risks may be limited as to the amount of coverage they can purchase). If, however, less than 40% of a local section applies, the insurance company will have the privilege of selection on the basis of health (unless 40% of the entire AWS membership has applied). (Any section with less than 100 members will be combined with another section for qualification purposes only.)

In the meantime, the insurance company has agreed to make the

AWS DIRECTORS-AT-LARGE

Term Expires	1960	1961	1962
	J. F. Deffenbaugh	A. A. Holzbaur	Jay Bland
	A. E. Pearson	D. B. Howard	F. G. Singleton
	C. M. Styer	C. E. Jackson	C. B. Smith
		J. L. York	J. R. Stitt

AWS DISTRICT DIRECTORS

District No. 1•New England	G. W. Kirkley	District No. 6•Central	J. N. Alcock
District No. 2•Middle Eastern	E. E. Goehringer	District No. 7•West Central	L. L. Baugh
District No. 3•North Central	J. W. Kehoe	District No. 8•Midwest	G. O. Bland
District No. 4•Southeast	E. C. Miller	District No. 9•Southwest	C. L. Moss III
District No. 5•East Central	H. E. Schultz	District No. 10•Western	F. V. McGinley
		District No. 11•Northwest	C. B. Robinson

AWS PAST PRESIDENT DIRECTORS

J. J. Chyle G. O. Hoglund C. P. Sander

This New **PLUG-IN** Welder Control

Lets You

ADD CONTROL FUNCTIONS AS YOU NEED THEM

A Wide Range of Plug-In Units Enables You to Add Components as Your Welding Jobs Change

HERE'S HOW YOU CHANGE YOUR BASIC CONTROL SIMPLY BY ADDING PLUG-IN UNITS

FOR WELDING MILD STEEL— BASIC CONTROL INCLUDES THESE PLUG-IN UNITS:

3B Timer
Relay Valve Control
Tube Firing Panel

FOR WELDING ALUMINUM— YOU ALREADY HAVE:

3B Timer
Relay Valve Control
Tube Firing Panel

YOU ADD THESE PLUG-IN UNITS:

Heat Control
Up-down Slope
Forge Delay

Every feature you want —for every welding job

- 22 standard units provide "custom" control for every welding requirement
- all units are plug-in type for quick change
- available in "all electronic" or "relay firing" versions
- auxiliaries for all conventional welding functions
- circuits include the latest safety features

***Write** for Bulletin SM-277* to Square D Company, 4041 N. Richards St., Milwaukee 12, Wisconsin

EC&M HEAVY INDUSTRY ELECTRICAL EQUIPMENT...NOW A PART OF THE SQUARE D LINE

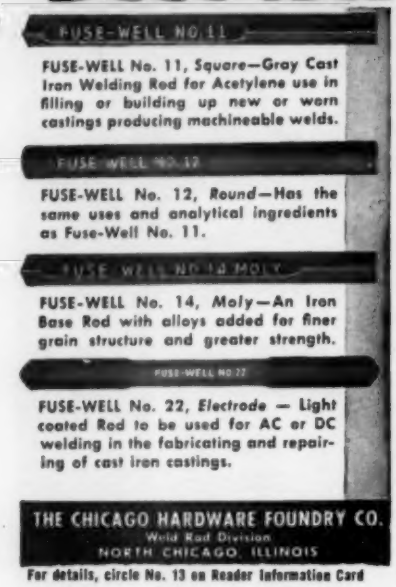
SQUARE D COMPANY

For details, circle No. 11 on Reader Information Card

When You Weld Cast Iron
Select the Correct

Fuse-Well

CAST IRON WELDING RODS
OR ELECTRODES


FUSE-WELL NO 11
FUSE-WELL No. 11, Square—Gray Cast Iron Welding Rod for Acetylene use in filling or building up new or worn castings producing machineable welds.
FUSE-WELL No. 12, Round—Has the same uses and analytical ingredients as Fuse-Well No. 11.
FUSE-WELL No. 14, Moly—An Iron Base Rod with alloys added for finer grain structure and greater strength.
FUSE-WELL No. 22, Electrode — Light coated Rod to be used for AC or DC welding in the fabricating and repairing of cast iron castings.

THE CHICAGO HARDWARE FOUNDRY CO.
Weld Rod Division
NORTH CHICAGO, ILLINOIS
For details, circle No. 13 on Reader Information Card

coverage effective for the insurable members after the first 100 acceptable applications from all sections of the SOCIETY have been received, so that there will be no undue delay in coverage for those members who are in good health.

The following are some of the outstanding advantages of this group insurance program:

1. The insurance of an individual member cannot be canceled by the company as long as he remains a member of the SOCIETY and the program remains in force. The loss of time plan, of course, must be dropped when a member retires, and the loss of time plan and major hospital-nurse-surgical plans can be carried up to the annual premium due date after a member reaches age 70. The senior plan will then be available.

2. The group insurance program will be offered to members at rates substantially lower than the cost of similar coverage under individual policies.

3. There will be no physical examination and the application will be an extremely simple one to fill out.

4. Once a certificate of insurance is validly in force, benefits cannot be reduced because of other insurance carried or because an insured performs duties of a more hazardous occupation.

5. The insurance program will provide world-wide coverage and a broad aviation clause.

6. If sickness disability begins after the effective date of a certificate of insurance, coverage is provided, regardless of the date of origin of the ailment. Once a certificate is validly in force, it cannot be changed to eliminate coverage of this ailment.

7. The major hospital-nurse-surgical plan will be available with the option of a $500 deductible, so as to eliminate duplication of benefits with a basic hospital expense plan a member may already carry. However, unless other coverage is of a catastrophic nature, this plan may be superimposed on a basic plan, even though there may be some duplication of coverage.

8. Benefits from the SOCIETY's insurance program will be paid regardless of any other insurance which the member may carry.

The success of the program will depend upon the interest and active support of our membership. The board of directors feels that this is a worthwhile project and it is urged that each member give the matter serious consideration.

FRED L. PLUMMER

Welcome

• Supporting Company

Effective September 1, 1959:

Pruden Products Co.
Evansville, Wis.

1959

Educational Lecture Series

AMERICAN WELDING SOCIETY

Chicago Section

PRACTICAL WELDING METALLURGY II

At . . . Chicago Bridge and Iron Co. Dome

1305 W. 105th St., Chicago, Ill.

Time . . . 7-9 p.m. Thursdays

Sept. 17—Low Alloy Steels, Part I
Richard Lee of Alloy Rods Co.

Sept. 24—Low Alloy Steels, Part II
Richard Lee of Alloy Rods Co.

Oct. 1—Stainless Steels, Part I
Wayne Wilcox of Arcos Corp.

Oct. 8—Stainless Steels, Part II
Wayne Wilcox of Arcos Corp.

Oct. 15—Aluminum Alloys
Fred Baysinger of Kaiser Aluminum & Chemical Corp.

For additional details write to:

Mr. R. E. Oller, *Chairman AWS Educational Activities Committee*
Commonwealth Edison Co.
72 West Adams, Room 800, Chicago 90, Ill.

NUCLEAR SYSTEMS
offers
CONTRACT RESEARCH
in

- **Non-destructive Testing**
- **Radiation Applications**
- **Thickness-Density Gaging**
- **Radiography**

Nuclear Systems is now developing a prototype scanning system for the high speed non-destructive inspection of very large solid propellant rocket engines. This program entails the application of thickness-density gaging to non-destructive testing, and is being sponsored by the Air Force through one of the largest producers of solid propellant fuels.

Similar systems should be applicable to less expensive inspection of heavy castings and weldments, and lead-filled radiation shields.

If you have a problem in any of the above areas, Nuclear Systems' engineers will be happy to discuss with you the establishment of an R & D program specifically designed to solve that problem in the most efficient, and therefore, most economical way.

PHILADELPHIA • CHICAGO • SAN FRANCISCO

NUCLEAR SYSTEMS
A DIVISION OF THE BUDD COMPANY, Philadelphia 32, Pa.
IN CANADA—TATNALL MEASURING AND NUCLEAR SYSTEMS, LTD.
46 HOLLINGER RD. • TORONTO 16, ONT.

Budd

For details, circle No. 12 on Reader Information Card

KEEPING YOU POSTED

by Fred L. Plummer

● This issue of the JOURNAL will reach you as AWS members gather in Detroit for our National Fall Meeting with headquarters at the Sheraton-Cadillac Hotel. Fine cooperation and advance planning by our Detroit arrangements committees under the leadership of A. E. Lindsey will insure success for the opening session devoted to the new "compact" automobiles, the sixteen technical sessions, educational and section officers conferences, plant tours, banquet, ladies program, board, council and committee meetings. The annual meetings of PVRC will be held at the same time under the guidance of National Chairman Tom Armstrong, Director Bill Spraragen and his associate Ken Koopman.

● Elsewhere in this issue you will find a statement about a group insurance program approved by your Board of Directors as a new and added service to AWS members. Read this article and the literature you receive from the administrator of the plan carefully to determine if this plan may be of value to you.

● You will also find in this issue a color insert showing the new United Engineering Center which will house your national headquarters sometime in 1961. Read the accompanying fund drive plans and proudly participate in the promotion of the profession-wide project.

● Plans for our Mid-Pacific Conference to be held in Hawaii following the Annual Meeting and Welding Exposition in Los Angeles next April 25th to 29th, will be announced at the Fall Meeting in Detroit. Watch for further announcements in future issues of the JOURNAL and plan to join fellow AWS members in this gay travel adventure.

● The Governing Council of the International Institute of Welding has accepted our invitation to hold its 1961 Assembly in New York in conjunction with our April 17th to 21st Annual Meeting and Welding Exposition. The American Council of IIW will meet at SOCIETY headquarters September 22nd. IIW President W. Edstrom will visit this country during October and confer with your Secretary. Mr. A. R. Jenkins, who has just completed a 3-year term as IIW vice president will also visit with us and inspect a number of fabricating plants during the same month.

● August 14th was the final day for receiving ballots covering approval of the simplified AWS By-laws. Approval was overwhelming with only 13 negative ballots and some 35 invalid ballots which were not marked or signed.

● The August issue of *Civil Engineering* included an interesting article "Welding Economy with Planned Connections" by Omer W. Blodgett. The May issue of the *Australian Welding Journal* paid a nice compliment to AWS by commenting on an announcement in their April issue "that in future, the style of technical articles will change to conform with AMERICAN WELDING SOCIETY practice."

● District directors have organized district committees to nominate representatives for the 1960–61 National Nominating Committee and also in certain districts to select nominees for the 1960–63 term as district director, and in all districts to select nominees for 1959–60 Meritorious Certificate Awards. Your section chairman or his appointed representative is a member of these committees. Help him by offering your suggestions as to names of capable individuals deserving of these honors and responsibilities.

● July mail included a card from Director Jim Alcock posted in Moscow which he was visiting as part of an extended European tour. Another AWS member, Tom Nast, left about August 12th for an extended visit to Russia.

● Returning delegates who attended the 1959 Assembly of the International Institute of Welding held in Opatija, Yugoslavia early in July and who have reported activities of the governing council and commissions to your Secretary include AWS Technical Secretary Ed Fenton, Commander Fred Munchmeyer of the Ship Structure Committee, Arthur Gatewood and George Place of the American Bureau of Ships, Frank Davis of the Atomic Energy Commission and T. Embury Jones. Others of the twenty-six official delegates and experts from the United States will submit written reports.

● Your Secretary spent July 30th in Philadelphia conferring with Vice-president Dave Thomas and Exposition Chairman Jim Norcross. He also had the pleasure of lunching with long time active AWS supporter R. D. Thomas, Sr. President Charlie MacGuffie and Vice-president Dave Thomas spent August 5th at headquarters planning for board and council meetings, and studying various SOCIETY projects and operating problems. Vice-president Al Chouinard called by phone August 13th to plan for a districts council meeting and discuss other SOCIETY activities. Education Activities Chairman Clarence Jackson visited headquarters August 4th to review progress on a number of these projects, plan for the educational conference in Detroit and discuss the symposium-type courses on special welding subjects which will soon be announced by your SOCIETY.

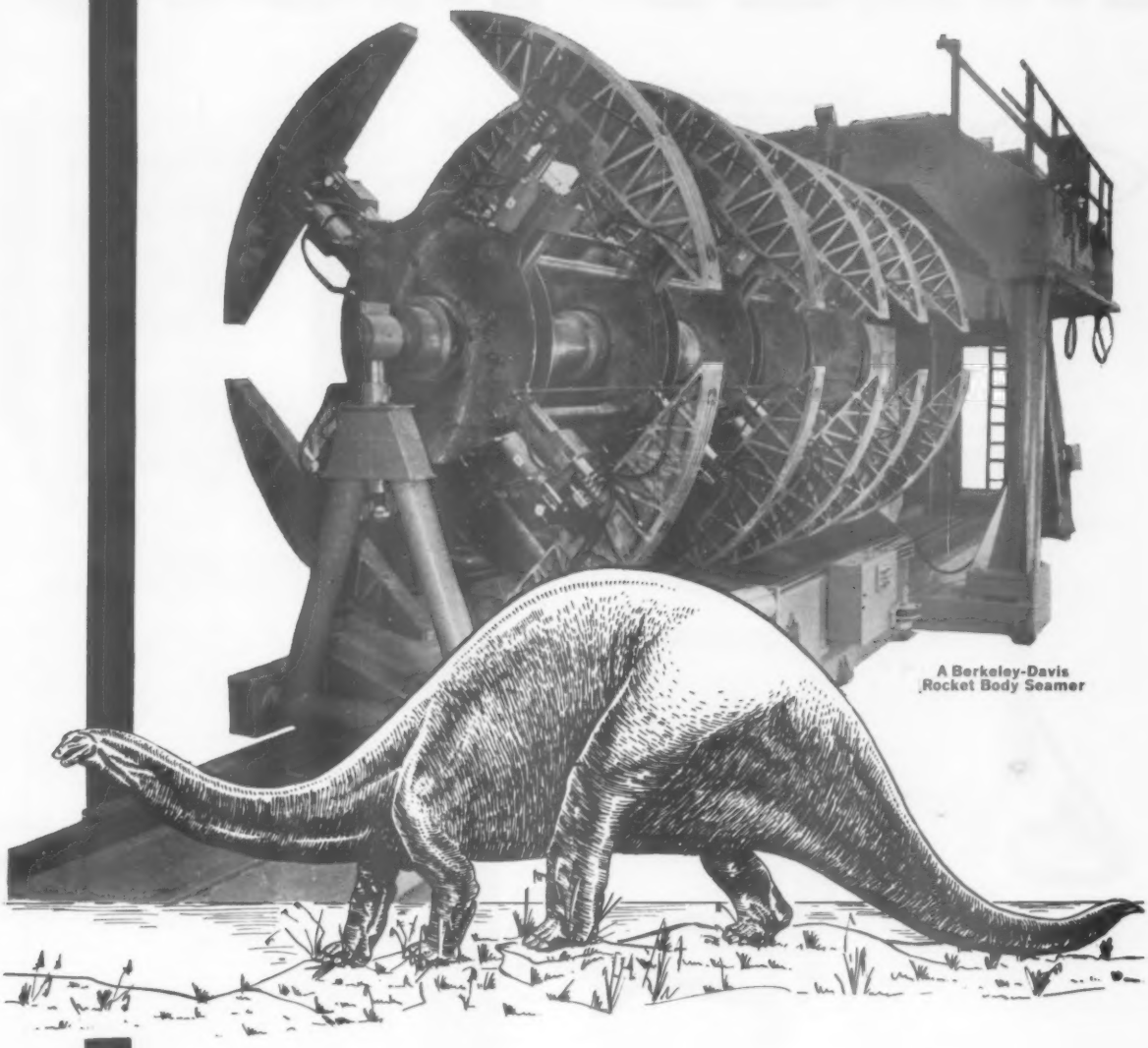
● During the summer your Secretary has frequently discussed the design of the new United Engineering Center with the architects, engineers and general contractor for this large tower building. Mr. Sam Bast of the engineering firm of Seelye, Stevenson, Value and Knecht is in charge of the engineers directly responsible for the structural design of the building, which will be supported by columns consisting of the heaviest wide flange steel section that is rolled (14 in., 424 lb) plus cover plates as thick as $3^1/_2$ in. The girder-to-column connections must resist high bending moments created by lateral wind loads. These connections, in fact the entire steel frame, will consist of efficient, economical welded construction.

● Carl H. Willer joined your headquarters staff on September 1st as assistant to Journal Editor Rossi. He replaces Bob Irving who has joined the staff of Iron Age magazine.

● On September 17th President MacGuffie, Director Kehoe and your Secretary met with the Niagara Frontier Section. Vice-president Thomas spoke to the Indianapolis Section on September 25th.

(Continued on page 1018)

BIGGER THAN BRONTOSAURUS



A Berkeley-Davis Rocket Body Seamer

. . . and as Modern as Tomorrow

BERKELEY - DAVIS, INC.

DANVILLE, ILL.

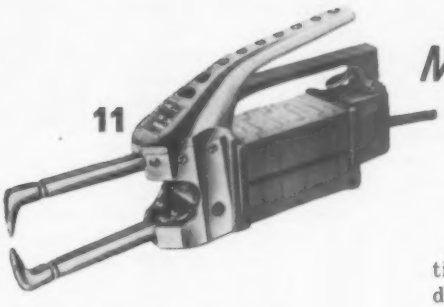
Affiliated with FEDERAL Machine and Welder Co.

For details, circle No. 39 on Reader Information Card

MEET M&T's

For details, circle No. 15 on Reader Information Card

NEW LINE



Murex Machines and Equipment for Better Welding

ALL NEW! And you'll find everything here from heavy-duty production machines to portable small shop outfits. Many have unique design features. All are made to equal or exceed the most rigid industry specifications. And all are manufactured with the same careful attention to quality you see in the line of Murex rotating welders and controlled arc power sources which are also available.

1. **AC Industrial Arc Welders** for heavy-duty production welding
2. **All-Purpose Welders** highly versatile units for any welding job
3. **Inert Arc AC Welders** for heavy-duty inert gas arc welding
4. **AC Arc Welders** for production, maintenance and shop welding
5. **AC Arc Welders** for medium duty welding
6. **AC Arc Welders** complete, portable welding outfit
7. **High Frequency Arc Stabilizer** for metallic arc welding
8. **High Frequency Arc Stabilizer** for inert gas arc welding
9. **High Frequency Arc Stabilizer** for spot, inert gas and metallic arc welding
10. **Arc Torch** for use with any DC or AC welder
11. **Portable Spot Welder** for sheet metal and wire

ATTENTION DISTRIBUTORS:

Learn how M&T is ready to help you profit from Murex machines and equipment. Write today.

M&T welding products
METAL & THERMIT CORPORATION
General Offices • Rahway, New Jersey

Interested in performance details and how you'll benefit? Then, for complete information, mail this coupon today.

METAL & THERMIT CORPORATION
General Offices: Rahway, New Jersey

I am particularly interested in the equipment checked below.

☐ Have representative phone for appointment. ☐ Send data sheets.

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11

Name_____

Title_____

Company_____

Address_____

City_____ State_____

For details, circle No. 15 on Reader Information Card

All-welded Steel Frame Building to House AWS Headquarters

Your AWS National Headquarters will be housed in the modern, *all-welded* United Engineering Center shown on the color insert appearing in this issue of the JOURNAL.

Before you read these lines former U. S. President Herbert Hoover will have turned the first shovel of earth at official ground-breaking ceremonies planned for October 1.

Construction schedule, data about the building, list of organizations which will establish headquarters in the center and a statement about the drive for funds appear together with the color picture.

In 1957 your Headquarters Housing Committee, chairmanned by Past-president Humberstone and including as members Past-presidents Sander and Fraser, our President MacGuffie and other directors, made a careful and exhaustive study of the relative advantages of alternate plans and locations for national headquarters. These studies covered the proposed new United Engineering Center in New York, independent headquarters in New York, in suburban areas near New York and in other cities such as Cleveland and Chicago.

In each location studies covered use of rented space, purchase of an existing building and purchase of land followed by the construction of a headquarters building. Facilities, services, costs, contacts with closely allied groups, printers and others supplying essential needs, travel times of staff, officer and committee members, moving costs, prestige, every significant factor was given consideration.

Recommendations of this committee were reviewed by all members of your Board of Directors. Following further study and discussion it was voted by the board of directors to accept the invitation to establish AWS Headquarters in the new United Engineering Center now being constructed in New York.

All groups which will occupy the new center are nonprofit organizations. Funds for construction are being subscribed by industry and by members of these organizations. Thus the building will not have to support heavy tax and interest charges and space can be made available at costs much lower than for comparable commercial buildings.

The United Engineering Trustees will hold title to the property on behalf of all the engineers who are supporting the project. All groups occupying the building will enjoy exactly the same privileges and responsibilities. One of the world's most complete engineering libraries, excellent meeting and exhibit rooms, and dining facilities will be housed in this building.

A group of distinguished engineers have been seeking contributions from industry. As of July 31st some 468 gifts totaling $4,456,444 had been pledged. The five founder societies have been conducting member campaigns for some time. As of July 31st 54,962 individuals had subscribed a total of $2,552,395, an average of about $46.50 per pledge.

Members of the American Institute of Chemical Engineers have already pledged more than their total quota of $300,000. Quotas for other founder societies are: ASCE $800,000, AIME $600,000, ASME $800,000 and AIEE $900,000. Members of these societies have already pledged more than seventy percent of these totals.

Your board of directors has agreed to seek a total of $60,000 from AWS members and sections. In a preliminary drive headed by Past-president Hoglund, fifty-two members have subscribed $3539 and eleven sections have pledged $3570 for a total of $7109 credited to AWS.

Honor sections are Philadelphia $1500, New York and New Jersey $500 each with more to come, Baltimore $300, Dayton $250, Hartford, Birmingham, Rochester, Carolina, Anthony Wayne and Indiana with pledges of from $50 to $150. Largest single individual gift is $1000.

Now is the time for each AWS member to do his part. Pledges may be paid over a period of three years, may be credited to AWS or in part to AWS and the remainder to one or more other groups.

Your campaign team will be headed by Vice-president Al Chouinard and our eleven district directors—J. N. Alcock, L. L. Baugh, G. O. Bland, E. E. Goehringer, J. W. Kehoe, G. W. Kirkley, F. V. McGinley, E. C. Miller, C. L. Moss III, C. B. Robinson and H. E. Schultz. These will be supported by the chairmen of our 84 active sections and their local workers. The drive can succeed easily if *you* and every other AWS member will do your part. Each section will be assigned a quota. Many sections of other societies have already pledged more than their quota. Almost twenty-five percent of the members of the founder societies have already participated. Watch future issues of the JOURNAL for progress reports. Will your section be the first to exceed its quota? Philadelphia is now ahead with a total of over $2500 pledged toward its goal of $2800. New York is second with over $1600. of its $2600 goal.

Fill in the pledge slip herewith and hand to your section chairman.

Fred L. Plummer

In consideration of the gifts of others I intend to give to

UNITED ENGINEERING CENTER BUILDING FUND

_____ Dollars $_____

Paid herewith $_____ Balance will be paid as follows

_____

Credit my gift to:

☐ AWS ☐ _____

Signed _____

Print Name _____

Address _____

COMING!
NEW United Engineering Center

UEC BUILDING FACTS — 18 stories high . . . 263,067 sq ft, gross, and 179,885 sq ft, net, almost twice as much net space as in the present 39th Street building . . . auditorium to seat 450 people . . . the world's most complete engineering library . . . the Engineering Index, the most comprehensive indexing and abstracting service for engineers . . . central services to avoid duplication of costs . . . Architects: Shreve, Lamb & Harmon Associates . . . Structural engineers: Seeyle, Stevenson, Value & Knecht . . . Mechanical and electrical engineers: Jaros, Baum & Bolles . . . Contractor: Turner Construction Company.

NEW

UNITED ENGINEERING CENTER

COMING! And indeed it is coming — the new United Engineering Center, the beautiful building as shown, in color, on the reverse side.

Commencement of construction in early fall, 1959 . . . Completion of construction by March, 1961 . . . Ready for occupancy by July, 1961 . . . these are the target dates for the new building.

The New United Engineering Center will rise and stand as a monument to a proud and noble profession. Just as its near neighbor, the United Nations on United Nations Plaza in New York City, stands as a symbol of world co-operation, the new United Engineering Center will stand as a symbol of engineering unity and co-operation in the United States. It will be the greatest center for engineering interests in the world. It will be a structure in which every engineer will have justifiable pride.

There is no question that the building will be built. But the drive for funds cannot be allowed to slow down. This message reaches you at a time when we have just passed the three-quarter mark in our fund campaign. The home stretch — and victory in this united drive — lie in the weeks ahead.

Now is the time for all campaign workers to make sure that all members of each section have at least been contacted. It is the time for all sections of all societies to strive for 100 per cent completion of their quotas. It is the time for those sections which already have reached their money goals to keep trying for 100 per cent membership contributions.

And it is also the time for those engineers who already have contributed to ask themselves: "Have I done my part? Have I given to the best of my ability?"

THE FUTURE HOME OF THESE ENGINEERING ORGANIZATIONS

American Society of Civil Engineers
American Institute of Mining, Metallurgical and Petroleum Engineers
The American Society of Mechanical Engineers
American Institute of Electrical Engineers
American Institute of Chemical Engineers
American Institute of Consulting Engineers
American Institute of Industrial Engineers
American Society of Heating Refrigerating and Air-Conditioning Engineers
American Welding Society
Illuminating Engineering Society
Society of Women Engineers
Engineering Index, Inc.
Engineers' Council for Professional Development
Engineers Joint Council
United Engineering Trustees, Inc.
Welding Research Council

EDUCATIONAL ACTIVITIES

EAC Announces Good News for Engineers

Plans for a series of courses or seminars for graduate engineers in specialized welding subjects are now under consideration by the Society. These plans are the result of a growing need to keep abreast of the trends and developments in our rapidly changing technological world. At a recent meeting of the executive committee of EAC it was decided to recommend that the first course be held in the early spring of next year with a fee charged to cover expenses.

For Whom Are the Courses Intended?

The courses will be slanted to the needs of the graduate engineer. They will cover welding subjects which are generally not available at our universities and colleges. In the ever-changing picture of American industry the educational needs of an engineer change and tend to become more specialized as he progresses and assumes more responsibility. His subordinates look to him for guidance and management expects to receive authoritative expert advice from him upon the operations under his control. Unless he learns about new developments he has no option but to recommend the older techniques with which he is familiar.

At the present time, it is extremely difficult, if not impossible, to obtain such training in the specialized fields of applied welding technology. If a company decides to change from other methods of joining to welded construction, and this is happening with ever-increasing frequency, it usually relies on its own engineers for the necessary development work. They need specialized knowledge and they need it in a hurry. The field of welding design is relatively new. There is a vast difference between "welding a design" and "designing for welding." The former is usually a conventional design fabricated by welding. "Designing for welding" makes use of the most modern concepts of design and permits great economies in weight and materials. A design engineer, unfamiliar with welding design technology, will automatically follow the time-honored rules applicable to conventionally-designed products.

Only a few company-sponsored courses and still fewer college courses are available which suit the requirements and schedules of engineers. The urgent need is for two- to five-day intensive courses on selected subjects which will give the engineer the specialized background and working knowledge he needs.

Where Will the Courses Be Held?

The initial courses will probably be held in New York. It seems inadvisable to organize courses in various parts of the country until sufficient experience has been obtained to determine a successful pattern based on geographical spheres of interest. Later it may be possible to hold courses of special interest to groups in the actual location where the majority resides.

Who Will Instruct?

Instructors will be drawn from sources where the latest information is available: industry, research and development laboratories, and colleges.

People who have lived with a process through its inception, development and field tests can bring a wealth of experience to those who are investigating its applications in their own operations. Fabricators who use such a process know its advantages, disadvantages and limitations. These are the sources from which instructors and lecturers will be drawn. They will be people who know their subject and, what is equally important, have the ability to impart their knowledge.

Subjects

Generally speaking, the choice of subject will be determined by need and urgency. At the present time we need courses for design engineers in fields as unrelated as foundries and electronics. Information on inert-gas metal-arc welding and many new semi and fully automatic processes is vitally needed today by many engineers. The techniques of ultrasonic welding and testing are not well understood by those outside of the welding industry and many engineers would welcome the opportunity to attend a short course on this subject. Welding metallurgy; weldability of metals; when to specify a given process, and why; inspection methods and equipment, are but a few of the subjects urgently needed by engineers.

Why Are Such Courses Necessary?

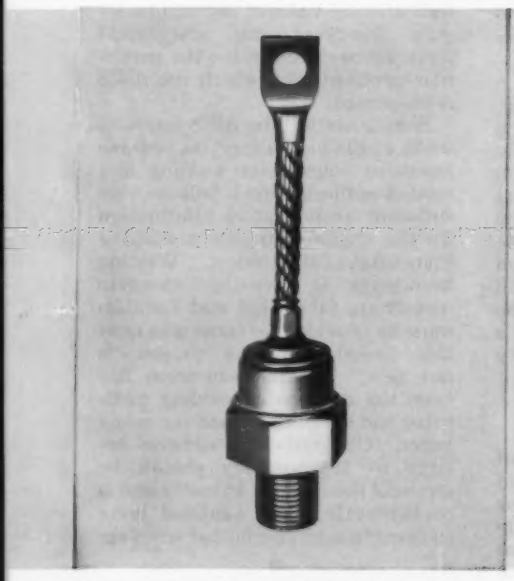
Many ask this question because they are puzzled at the inability of our universities, colleges and technical institutes to provide adequate instruction. The fact is we have reached a stage in our economic development when educational standards, developed to satisfy the needs of a previous era, no longer meet the needs of a world in which technology plays so great a part. In a four years' college course, it is utterly impossible to do more than supply the fundamentals, the basic knowledge upon which the graduate engineer can build. Some universities, such as Ohio State, are extending their curriculum to cover five years and the increased demand for their graduate welding engineers indicates the value of this additional year. However, our educational institutions cannot solve the particular problem with which the AWS is concerned.

Simply stated, the AWS hopes to make available the shortest possible intensive courses on welding and related subjects which will provide sufficient authoritative information for the engineer to gain a working knowledge of the subject. Welding knowledge is essential wherever metals are fabricated and facilities must be provided for those who need this knowledge. The project is not new. Welding education has been the concern of welding institutes and societies abroad for many years. Obviously, the national society in any country should be aware of the needs of industry and is probably the most qualified body to provide such specialized training.

The Educational Activities Committee of the AWS will welcome comments on this subject of graduate welding education to meet the needs of our engineers. Please address your comments to the Education Secretary, AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

new . . . Silicon Type WS

200, 300, 400 and 500 Amperes
230/460 Volts
60% Duty Cycle



Silicon diodes in the three-phase, full-wave rectifier are the heart of the WS welder. These diodes have a capacity far in excess of the rating for the welder and are hermetically sealed against dust, oil, water and acid fumes by a new bonding process. Each diode is thoroughly tested before and after insertion in the bridge.

Watch Westinghouse for New Developments in Welding

For details, circle No. 35 on Reader Information Card

Rectifier Welder

- *Maximum Performance at Minimum Cost*
- *Highest Degree of Electrical Efficiency*
- *Most Compact Welder in the Industry*
- *Extremely Low Maintenance*

The Type *WS* silicon rectifier welder reflects engineering skill of the highest order. This welder is designed for maximum performance and reliability. It is a product of experience—developed in the Westinghouse laboratories and tested in the field under a variety of conditions. The welder you purchase will be checked out in every detail before it leaves our factory. Every conceivable precaution has been taken to assure you of a faultless piece of equipment.

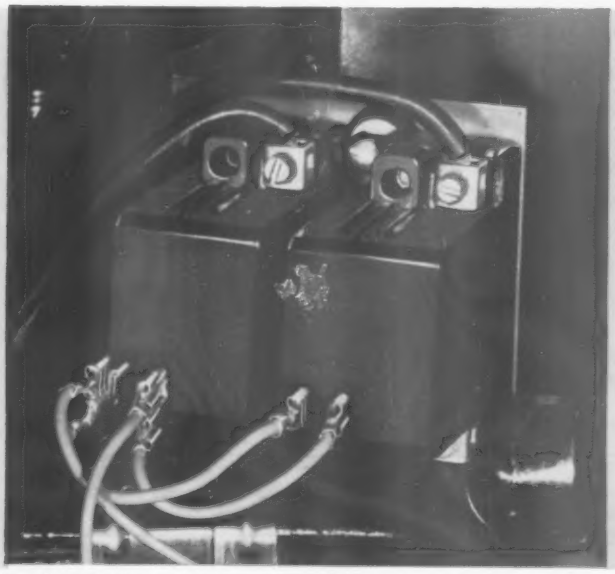
Westinghouse pioneered this completely new concept in industrial welding machines over 10 years ago. Since that time another refinement of the rectifier-type welder was achieved by Westinghouse through the use of silicon diodes. The ultimate in silicon rectifier machines is the Westinghouse Type *WS*.

No other welder on the market has the electrical circuitry to produce sound quality welds as consistently as the *WS*. It provides easier starting, arc stability and maximum drive. Silicon rectification means top welding performance.

The *WS* is the lightest, smallest machine on the market. It is easy to handle and is a space saver. Its bonderized steel casing, protected by baked-on enamel, gives it a weatherproof construction. The high-quality materials in this welder will render long life and trouble-free service.

Learn more about this reliable source of power for welding!

Contact your nearest franchised Westinghouse welding distributor—or write: Welding Division, Westinghouse Electric Corporation, 4454 Genesee Street, Buffalo 5, New York. J-22150



The inverse time relay shown here allows adequate time delay for arc starting at high current setting and freedom from nuisance power interruptions—yet it protects against serious short circuit faults. Capacitors divert and store peak, high-value, short-time voltage spikes that occur when electrical current is broken.

The Type WS has virtually no moving parts to wear out; thus, replacement is at a minimum. The easy access panel shown here makes routine maintenance and air cleaning of the rectifier bridge a fast, simple operation. Be cost-wise, avail yourself of this extremely low maintenance!

YOU CAN BE SURE... IF IT'S Westinghouse

WATCH "WESTINGHOUSE LUCILLE BALL-DESI ARNAZ SHOWS" CBS TV FRIDAYS

For details, circle No. 35 on Reader Information Card

SECTION NEWS AND EVENTS

As Reported to Catherine M. O'Leary

Minnesota

HOLD WELDING SHOW

Minneapolis—The *Northwest* Section, in cooperation with the William Hood Dunwoody Institute sponsored a two-day welding show on September 21st and 22nd at the Institute in Minneapolis. Live demonstrations and technical sessions formed the program, which was well attended. Thirteen manufacturers of welding and associated equipment were on hand to demonstrate their products and six technical sessions were presented on various subjects of interest.

Ohio

ANNUAL PICNIC

Dayton—One hundred and thirty members and guests attended the *Dayton* Section Annual Picnic held June 16th at the Inland Activities Center.

Walter Bruns and his committee provided volley ball and shuffleboard games prior to a delicious steak supper.

Bingo and dancing completed the evening.

ELECTION OF OFFICERS

Mahoning Valley—The annual spring election of officers for the *Mahoning Valley* Section resulted in the following members being elected officers or members of the executive committee. The new chairman for the year is Emmet Craig of Federal Machine and Welder Co.; first vice-chairman, Ralph Hoffman of Hoffman Iron and Steel Co.; second vice-chairman, Jack Glass of Wean Manufacturing Co.; secretary-treasurer, Robert Foxall of Federal Machine and Welder Co.

The remaining members of the executive committee are; Jack Huna of Taylor-Winfield Corp., Fritz Forsthoefel of Lincoln Electric Co., Forrest Johnson of American Welding & Manufacturing Co., Jim Liptak of Chicago-Bridge & Iron, Mike Bushwack of Warren G. Harding High School, Ed Phelps of A. O. Smith and Jack Manternach of

AT DAYTON PICNIC

Outgoing Chairman "Dick" Stratton welcomes members and guests to the Annual picnic sponsored by the Dayton Section on June 16th

SECTION MEETING CALENDAR

OCTOBER 7

NIAGARA FRONTIER Section. Joint meeting with Canadian Welding Society, Niagara Falls, Canada.

TULSA Section. "Cutting Equipment and Natural Gas Cutting," Robert Hughes, Linde Co.

OCTOBER 8

IOWA-ILLINOIS Section. LeClaire Hotel, Moline, Ill. "Welding of Missiles," Speaker from Progressive Welder Corp.

OCTOBER 13

DAYTON Section. "New Developments in Inert Gas Welding," Thomas McElrath, Linde Development Lab.

NEW YORK Section. "Welded Pressure Vessels," Norman Block, Foster Wheeler Corp.

OCTOBER 14

OKLAHOMA CITY Section. Dinner meeting, Swyden's Restaurant. C. I. MacGuffie, National President; F. L. Plummer, National Secretary.

OCTOBER 16

MARYLAND Section. "Maintenance Welding" C. C. Keyser, Bethlehem Steel Co.

OCTOBER 19

PHILADELPHIA Section. Engineers Club, 8:00 P.M. Monthly Technical Meeting. "Welding Power Sources," A. E. Johnson, A. O. Smith Corp.

ROCHESTER Section. Visit the Delco Appliance Division of General Motors, Rochester, N. Y.

OCTOBER 20

OLEAN-BRADFORD Section. Emery Hotel, Bradford, Pa. Dinner 7:00 P.M. "The Latest Developments in Heliarc Cutting," Dr. G. W. Oyler, Linde Co.

TOLEDO Section. Toledo Yacht Club. Dinner 6.00. Meeting 8.00. "Large Weldments Fabrication," J. L. Lang, Lukens Steel Co.

YORK CENTRAL-PENNSYLVANIA Section. "Types of Power Sources Used in Welding and Their Applications," Arthur Gast, Miller Electric Co.

OCTOBER 27

SANTA CLARA VALLEY Section. "New Brazing Applications," R. C. Bertossa, Pyromet Corp.

NOVEMBER 4

SUSQUEHANNA VALLEY Section. Dinner meeting. 6:45. Foot Hills Manor, Shickshinny, Pa. "Safety in Welding and Cutting" A. N. Kugler, Air Reduction Sales Co.

TULSA Section. "Various Welding Processes," speaker to be announced.

NOVEMBER 6

OKLAHOMA CITY Section. Plant Visit-Adams Hardfacing Co., Guymon, Okla.

NOVEMBER 10

NEW YORK Section. Victor's Restaurant. Dinner 6:15. Program 7:15. "Aluminum Welding, Past, Present and Future," I. A. MacArthur, Olin Mathieson Chemical Corp.

DAYTON Section. Plant Tour, Hobart Brothers Technical School, Troy, Ohio.

NOVEMBER 12

IOWA-ILLINOIS Section. LeClaire Hotel, Moline, Ill. "A Glimpse at the Future of Welding," President C. I. MacGuffie, Secretary Fred Plummer, AMERICAN WELDING SOCIETY.

NOVEMBER 17

OLEAN-BRADFORD Section. The Castle, Olean, New York. Dinner 7:00 P.M. "A Cross Section of Fabrication by B-L-H, Eddystone Division," F. P. Iapalucci, Baldwin-Lima-Hamilton Corp.

TOLEDO Section. Toledo Yacht Club. Dinner 6:00. Meeting 8:00. "Aluminum Welding, Past, Present and Future," I. A. MacArthur, Olin Mathieson Chemical Corp.

YORK CENTRAL-PENNSYLVANIA Section. "Welding of the World's Largest Undersea Craft, The Atomic Submarine Triton," George W. Kirkley, Electric Boat Division, General Dynamics Corp.

NOVEMBER 19

MADISON Section. Joint Meeting with University of Wisconsin. T. B. Jefferson, The Welding Engineer.

NOVEMBER 20

MARYLAND Section. "Welding and Brazing and Fuel Element Construction" P. Patriarca, Oak Ridge National Laboratory.

NOVEMBER 24

SANTA CLARA VALLEY Section. "CO_2 Welding of Steel" R. W. Tuthill, Air Reduction Company.

Editor's Note: Notices for January 1960 meetings must reach JOURNAL office prior to October 20th, so that they may be published in the December Calendar. Give full information concerning time, place, topic and speaker for each meeting.

Heltzel Iron & Steel Co.

To encourage the art and science of welding in the local high schools, the Mahoning Valley Section initiated, this year, a monetary award and prize certificate to the most outstanding senior in the welding class at Warren G. Harding High School in Warren, Ohio. This high school is equipped with a very modern welding laboratory and this high school student award was based upon top achievement in attendance, scholastic record over a two year period, AWS manipulative test, the student's general citizenship and a written examination. The first winner was John Howell and his award was presented to him by Mike Bushwack of the Mahoning Valley executive committee at the annual high school award assembly.

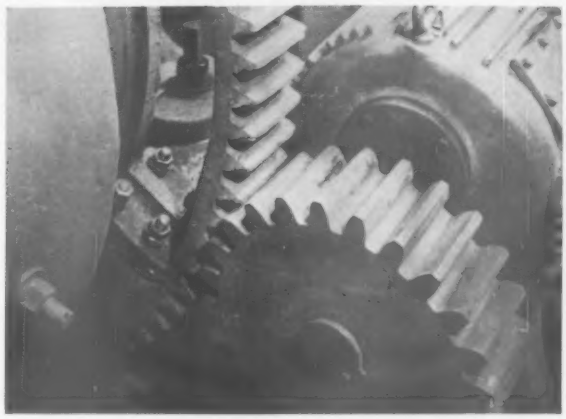
This award will be presented every year to the top senior in the welding class and it is hoped to expand this award throughout the other high school districts in the Mahoning Valley.

To finish off the 1958–59 season and also as an aid in continuing the interest in the AMERICAN WELDING SOCIETY for the coming year, the Mahoning Valley Section had its first annual Summer Stag Affair on August 7th at the Eastern Ohio Conservation Club near Canfield, Ohio. Although wet weather decreased the expected attendance, a total of 85 men attended this robust affair. A plentiful supply of food, catered by a local agency and the many cases of free beer aided in giving the evening a festive atmosphere for this successful social outing.

Texas

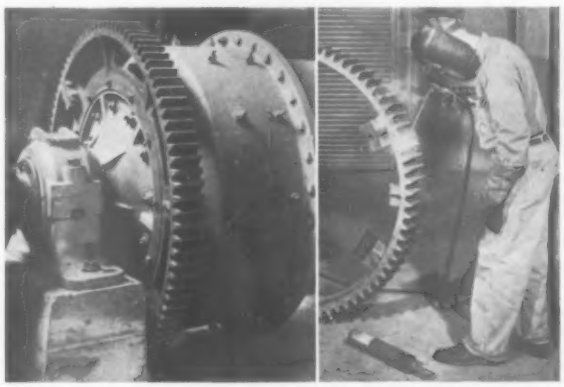
SAFETY

San Antonio—Forty-eight members of the *San Antonio* Section gathered here at Capt. Jim's Cafe on August 3rd. Following dinner, the section heard the speaker, H. E. Bendele, who has been with the City Public Service Board of San Antonio for 13½ years, and is the safety supervisor for the Power Plant Division. After a most interesting talk on safety, Mr. Bendele showed two films—one entitled "Safety for the Welder" describing safety measures to be observed by all welders; and other "To Live in Darkness" based on accidents that could happen due to the lack of precaution. Both films were excellent and enlightening to those present.



Colmonoy Hard-Surfacing Makes Spur Gears Last Thirty-five Times Longer

Spur gear life of 5000 hours is now obtained by the operator of the ball mill shown, instead of a previous gear life of only 140 hours. The reason for this tremendous jump in service life: The application of Colmonoy No. 2 hard-surfacing electrodes to the gear teeth. And it costs less to hard-surface a worn gear than to buy a new one!



Gear wear was accentuated because this mill processes hard compounds, causing extremely abrasive particles to fall on the meshing gear teeth.

Protecting spur gear teeth by arc welding deposits of Colmonoy No. 2. These low-hydrogen DC electrodes weld fast, require low amperages.

Wherever excessive metallic wear exists, there is an opportunity to cut costs. You know where such wear exists. Colmonoy sales engineers know what to do about it. Call one. Or write to Detroit about your problem part.

Ask for Colmonoy Hard-Facing Manual No. 79.

HARD-SURFACING AND BRAZING ALLOYS

WALL COLMONOY CORPORATION

19345 John R Street • Detroit 3, Michigan

BIRMINGHAM • BUFFALO • CHICAGO • HOUSTON • LOS ANGELES
MORRISVILLE, PA. • NEW YORK • PITTSBURGH • MONTREAL • GREAT BRITAIN

For details, circle No. 17 on Reader Information Card

New Members

EFFECTIVE AUGUST 1, 1959

MEMBERSHIP CLASSIFICATION

A—Sustaining Member
B—Member
C—Associate Member
D—Student Member
E—Honorary Member
F—Life Member

TOTAL NATIONAL MEMBERSHIP

Sustaining Members	194
Members	6,196
Associate Members	5,617
Student Members	233
Honorary Members	10
Life Members	16
Total	12,266

CAROLINA
Autry, J. O. (B)

CHICAGO
Potter, Martin L. (B)

CINCINNATI
Kukuk, Herman W. (B)

CLEVELAND
Dermott, Ralph G. (C)

COLORADO
Pruitt, Edsel L. (B)

DAYTON
Hughes, Donald M. (C)

DETROIT
Katzer, Albert E. (B)

HOLSTON VALLEY
Hite, James H. (C)
Lawson, Starling L. (B)
Parsons, L. M. (B)

HOUSTON
Johnson, Joseph Emmett (B)
Le Bleu, Charles C. (C)
Massey, J. E. (B)
Moon, W. U. (B)
Scott, William W. (B)
Smith, Louis A. (C)
Wilkerson, Clarence (C)

INDIANA
Masters, Joseph E. (B)

IOWA-ILLINOIS
Long, Ralph E. (B)
Rissler, Niel J. (C)

KANSAS CITY
Clipsham, Robert B. (C)

LOUISVILLE
Kurk, Elmer F. (B)

MAHONING VALLEY
Johnson, Lee B. (B)
Millsop, John A. (B)
Philson, Robert E. (B)
Robson, Leonard K. (B)

MARYLAND
Morris, Lawrence D. (C)

MICHIANA
Werner, Roger W. (B)

NEW HAMPSHIRE
Lee, Bernard E. (B)

NEW JERSEY
Douglas, Thomas L. (B)
Rappelyea, Erdman W. (B)

NEW YORK
Andrews, Albert M., Jr. (C)
Cirami, Louis M. (B)
Hall, William C. (B)

NORTHEAST TENN.
Prislinger, Joseph J. (C)

PHILADELPHIA
Hurlebaus, Richard P. (C)

PITTSBURGH
Jeffers, Bobby Russell (C)

PROVIDENCE
Gillerin, Richard E. (C)
Lees, John W. (B)

PUGET SOUND
Passic, Alex (B)
Poage, Leland Berne (B)

RICHMOND
Maloney, George S. (C)

SAGINAW VALLEY
MacAbee, Philip T. (D)

SAN ANTONIO
Cole, Joseph G. (B)
Deason, W. N. (B)
Payne, H. E. (B)
Powell, Henry P. (B)
Williams, Rufus (B)

SAN DIEGO
Haines, George Ray (B)

SANGAMON VALLEY
Clarkson, Robert A. (C)
Glasscock, David G. (B)

SYRACUSE
Mueller, Roger P. (C)

TOLEDO
Simmons, Alan D. (B)

YORK CENTRAL PA.
Long, Charles J. (C)

MEMBERS NOT IN SECTIONS
Hirschler, Esteban J. (B)
McCarron, Ronald Patrick (C)
Nadler, Kurt (B)
Vila, Rudolfo (B)

Members Reclassified During August

MAHONING VALLEY
Butler, W. J. (C to B)

SAN FRANCISCO
Dadian, Thomas E. (C to B)

KEEPING YOU POSTED

Continued from Page 1006

● Following the meeting in Detroit September 28th to October 1st, your Secretary and Asst. Secy. Frank Mooney will fly to Los Angeles to meet with Section Chairman R. C. Hayes, L. A. Convention Chairman C. P. Sander and their local arrangements committee chairmen to plan for our 1960 meetings. Final detail plans for the hotel and exposition hall facilities, convention bureau and public relation and other contacts will be completed.

● Staff Member Mooney will then start a well-earned vacation as your Secretary travels east, stopping in Denver October 8th for a meeting with our AWS section in the mile-high city. The following week President MacGuffie will join your Secretary for meetings with AWS sections in Oklahoma City and St. Louis on October 14th and 15th. Mr. J. F. Lincoln and your Secretary will meet with the Wichita Section on October 12th.

● On October 21st to 22nd President MacGuffie, Vice-President Thomas, your Secretary and other staff members will join Director Kirkley at the New England Welding Conference and Exposition to be held in Hartford, Conn. with Section Chairman W. A. Duncklee in charge of arrangements.

Abstracts of Current PATENTS

prepared by Vern L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington, D.C.

2,839,663 — WELDING APPARATUS— James T. McCollom, Anaconda, Mont., assignor to the Anaconda Co., a corporation of Montana.

McCollom's patent is on specialized apparatus for depositing a refractory metal lining on the interior surface of the ladle. The apparatus includes special positioning means that include a carriage for movement along an upper portion of the ladle and with an arc welding apparatus being suspended from the carriage to exten into welding position with respect to the inside surface of the ladle.

2,839,664—SPOT WELDING GUN— Ralph D. Fagge, Detroit, Mich.; Sophie A. Fagge, administratrix of the estate of said Ralph D. Fagge, deceased.

In this spot welding gun, a frame structure with an elongated rectilinear guideway is provided and a stationary electrode holder is mounted on such frame. A reciprocatory motor is mounted on the frame and has a reciprocating plunger mounted to have its axis of reciprocation disposed parallel to the guideway and movable towards and away from the stationary electrode holder. A movable electrode holder is mounted on the plunger structure in alignment with the stationary electrode holder. Other means complete the gun and such means include a guide element for preventing rotation of the movable electrode holder during reciprocation and during replacement of electrodes in such movable electrode holder.

2,839,665 — PNEUMATICALLY OPERATED WELDER HEAD CONSTRUCTION Eugene A. Wolfbauer, Mount Clemens, Mich., assignor to Savair Valve & Equipment Co., Detroit, Mich., a corporation of Michigan.

In this patent, a novel combination particularly directed to a specialized control cylinder is disclosed for controlling movement of a welder head.

2,839,666—WELDING HEAD—Ernie L. Launder, Montebello, Allen W. Loudon, Downey, and Max Frederick, Jr., Whittier, Calif., assignors to H. & L. Tooth Co., Montebello, Calif., a corporation of California.

In this patent, a new head for a welding machine adapted to apply a weld to the periphery of rectangular assemblies of parts and the like is disclosed. The head includes rod feeding means, and mounting means carrying the feeding means laterally offset from a vertically disposed axis of rotation. A rod guiding means is carried by the feeding means and depends therefrom on an axis angularly related to and intersecting the axis of rotation of the mounting means at the point of weld.

2,839,819 — WELDABLE SINTERED MOLYBDENUM — William N. Platte, Boston, Pa., assignor to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

Platte's patent is on a specialized process for producing a sintered molybdenum compact that can be arc welded.

2,840,016—ADJUVANT POWDER CONTROL FOR FLAME CUTTING—Alfred F. Chouinard, Chicago, and Edward P. Spencer, Cary, Ill., assignors to National Cylinder Gas Co., Chicago, Ill., a corporation of Delaware.

This patent is on apparatus used in thermochemically cutting metal by the action of heating flames. A high pressure oxygen stream is provided and powdered adjuvant material is delivered to the work with a carrier gas supplied to the material under pressure. The carrier gas is so supplied to the hopper containing the adjuvant material that such material can be stored under pressure and the valve means permit storage of the material under predetermined gas pressure without loss of carrier gas during storage conditions.

2,840,685—METHOD OF ELECTROWELDING AND PRODUCTS MADE THEREBY— Paul Muller, Halle (Saale), Germany, assignor to VEB (K) Schweisswerk Halle, Halle (Saale), Germany.

This particular patent is on a method of welding with an entirely covered electric arc on ferrous base pieces, particularly cast iron base members. A welding area of a cast iron base is preheated to about 600° C and a layer of liquefied slag-powder of a melting point below that of the cast iron base is applied to the preheated welding area. An arc-producing electrode made from cast iron metal is inserted in this slag bath and then an electric arc is initiated between the electrode and the workpiece. This liquid slag layer is maintained during the entire welding process without withdrawing any of the slag.

2,840,686—HIGH-SPEED RESISTANCE WELDING CONTROL—Hubert W. Van Ness, East Aurora, and William E. Large, Lancaster, N. Y., assignors to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

In the patented control circuit, a first capacitor and a second capacitor are provided, while first, second and third electric discharge devices are also present in the control system. The apparatus is so arranged that a timing signal can be impressed on the control electrode of the third device.

2,840,687—WELDING APPARATUS— Walter S. Rae, Jr., Shreveport, La.

The present patent is on apparatus for use in joining the end of a pipe line with a pipe section. First a vehicular support is provided that has a beam thereon for receiving the end of the pipe line and a pipe section to position them in end-to-end relation. Other means pivotally position the beam to permit it to tilt to accommodate the natural curvature of the end of the pipe line, and to position the pipe line and pipe section in abutting position for welding action thereon.

2,840,761—HIGH-FREQUENCY WELDING STABILIZER—Clifton S. Williams and William E. Pakala, Pittsburgh, Pa., assignors to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

The present patent relates to a spark gap oscillator control circuit in welding action, and a spark gap is included along with other specialized members including capacitive means, and inductive means connected in series across the spark gap. Resistive means are present and are connected in a circuit so that the rate of charging of the capacitive means through the resistive means is so low as to permit the gap to deionize between successive discharges when the gap has become non-conducting after a train of oscillations.

2,840,789—ARC WELDING APPARATUS —Joseph F. Miller, Buffalo, N. Y., assignor to Westinghouse Electric Corp., East Pittsburgh, Pa., a corportion of Pennsylvania.

Miller's patent covers a special variable reluctance core assembly for use in arc welding operations.

2,841,678—HIGH-FREQUENCY INDUCTOR ARRANGEMENT FOR CONTINUOUS SEAM WELDING—Lloyd A. Thorson, Cuyahoga County, Ohio, assignor to the Ohio Crankshaft Co., Cleveland, Ohio, a corporation of Ohio.

This patent relates to a special high-frequency inductor arrangement for inducing welding currents to flow in the sides of and between the edges of a continuously moving C-shaped metallic tube as the edges are continuously brought together at a predetermined point in the path of travel. The patent covers a special shaping and positioning of the current conductors converging toward each other at a predetermined welding point in the tube path.

2,841,687—METHOD OF APPLYING HARD-FACING METALS—Kenneth E. Richter, Morristown, N. J., assignor to Union Carbide Corp., a corporation of New York.

Richter's patent is on a method of hard facing a metal workpiece and it teaches a method including striking an arc between a nonconsumable electrode and the bottom of a groove in the workpiece to form a weld puddle. A stream of hard-facing particles are projected through the shielding gas supplied to the weld puddle and the arc is progressed along with the gas and hard-facing particle stream along a line of weld on the workpiece. The electrode is oscillated with relation to the line of weld and low carbon ferrous metal is fed into the leading edge of the weld puddle in the groove to reduce the tendency to crack in the deposited metal at the bottom of the groove.

2,841,688—METHOD OF APPLYING A COPPER BAND TO A METALLIC SURFACE—Donald R. Andreassen, Waterloo, and Irving Herman, Cedar Falls, Iowa, assignors to Chamberlain Corp., Waterloo, Iowa, a corportion of Iowa.

This patent has a process to apply a seamless copper band to a cylindrical element and in it the cylindrical element is positioned for rotation and a pair of copper wires are separately fed at an angle toward each other adjacent the cylindrical element. One wire is energized as the hot electrode and the other wire is fed into the welding arc to melt the wires and weld the copper to the cylinder while rotating the cylinder.

2,841,689—TUBULAR SPRING WELDING ELECTRODE—Carl A. Van Pappelendam, Rivera, Calif., assignor to North American Aviation, Inc.

This new structure relates to an electrode, means supporting the electrode and an electrode base for the support means. A welding tip is provided and resilient means connect the electrode base to the welding tip to carry current and cooling fluid to the welding tip. Other means on the support hold the resilient means at a predetermined tension.

2,841,690—CONTACT PIN AND METHOD FOR FLUORESCENT LAMPS—Robert A. Kuebler, Cleveland Heights, Ohio, assignor to General Electric Co., a corporation of New York.

This patent is on a specialized welding method to provide a connection between a tubular metal contact pin and the end of a metal inlead wire. The method includes the steps of providing the contact pin with an extended end having an outer termination of low thermal mass and defining an opening of restricted diameter of greater length than the wall thickness of the portion of the pin defining the opening. The wire is threaded through the bore of the pin with the end of the wire within the restricted opening and welding action is thereafter effected as specifically outlined in the patent.

Current Welding LITERATURE

For copies of articles, write directly to publications in which they appear. A list of addresses is available on request.

Aluminum-Magnesium Alloys

New 5XXX Aluminum Alloys—Strong and Weldable, R. T. Myer and D. R. Cheyney. *Matls in Design Eng.*, vol. 50, no. 1 (July 1959) pp. 91 and 95.

Electric Transformers

When Resistance Welding . . . Sealed, Plastic Transformers Keep Maintenance Costs Low, W. Emaus. *Welding Engr.*, vol. 44, no. 7 (July 1959), pp. 32–33.

Flame Hardening

Flame Hardening by Oxygen—Town Gas Processes. *Heating*, vol. 21, no. 161 (Apr. 1959), pp. 126–127.

Gas Welding

Hydrogen-Nitrogen Trifluoride Torch, H. H. Rogers. *Indus. & Eng. Chem.*, vol. 51, no. 3 (March 1959) pp. 309–310.

Hard Surfacing

Hardfacing with Cobalt-Base Alloys, G. Grainger. *Cobalt*, no. 3 (June 1959) pp. 3–15.

Heat Exchangers

Resistance Welded Tube Joints in Heat Exchangers, J. J. Mueller. *Metal Progress*, vol. 74, no. 6 (Dec. 1958), pp. 106–111.

Machine Design

Aids to Efficient Machine Design in Welded Steel. *Lincoln Electric Co., Cleveland, Ohio*, 1958, 92 pp., Price $1.00.

Magnets Manufacture

Manufacture of Magnet Sectors for Harwell Proton Synchroton. *Machy. Market*, no. 3053 (May 21, 1959) pp. 23–26.

Marine Engines

Welding in Marine Engineering, J. A. Dorrat. *Inst. Mar. Engrs.—Trans.*, vol. 71, no. 3 (March 1959) pp. 69–88 (discussion) 89–95; see also abstract in *Motor Ship*, vol. 39, no. 464 (Jan. 1959) pp. 502–504.

Missiles

Speed Missile Parts Output With Induction Heating, L. C. Porter. *Iron Age*, vol. 183, no. 6 (Feb. 5, 1959), pp. 86–87.

Nickel Alloys

Some Aspects of Metal Arc Welding of Monel, M. K. Williams. *Welder*, vol. 28, no. 137 (Jan.–Mar. 1959), pp. 7–9.

Sandwich Construction

Spot-Welded Corrugated Sandwich Construction for Aircraft. *Machy.* (Lond), vol. 94, no. 2423 (Apr. 22, 1959) pp. 876–888, no. 2430 (June 10) pp. 1301–1306.

Tanks

New Highly Productive Method of Building Jackets of Cylindrical Steel Storage Tanks with Vertical Axis, V. Macku and K. Fila. *Czechoslovak Heavy Industry*, no. 1 (1959) pp. 22–27.

Tantalum

Tantalum Breaks Through, with New Production and Fabrication Techniques, B. Payne. *Am. Mach.* vol. 103, no. 11 (June 1, 1959) pp. 109–111.

Testing

Fillet Welds Subjected to Bending and Shear, F. E. Archer, H. K. Fischer and E. M. Kitchen. *Civ. Eng.* (Lond), vol. 54, no. 634 (April 1959) pp. 455–458.

Testing

High Intensity Cobalt Container for Industrial Radiography. *Metallurgia*, vol. 59, no. 356 (June 1959) pp. 311–312.

Testing

Hot Cracking of Mild Steel Welds, P. W. Jones. *Brit. Welding J.*, vol. 6, no. 6 (June 1959) pp. 269–281.

Testing

Investigation of Hot Cracking in Low-Alloy Steel Welds, P. W. Jones. *Brit. Welding J.*, vol. 6, no. 6 (June 1959) pp. 282–290.

Tube Manufacture

Large Electric Resistance Welded Steel Tubes. *Engineer*, vol. 207, no. 5378 (Feb. 20, 1959) pp. 298–299.

Welded Bridges

Inspection Methods for Welded Highway Bridges, L. Grover. *Roads & Streets*, vol. 102, no. 3 (March 1959) pp. 121–123, 128, 181.

Welded Steel Structures

Consider Residual Stresses When Welding, R. E. Holt. *Welding Engr.*, vol. 44, no. 6 (June 1959) pp. 66, 68.

Welding

How to Weld Tool Steels, J. J. Chyle. *Tool Engr.*, vol. 42, no. 6 (June 1959) pp. 83–91.

Welding Machines

Tape Guides Resistance Welder Through Complex Assembly. *Iron Age*, vol. 183, no. 13 (March 26, 1959) pp. 154–155.

Survey Results

If you've kept up with your reading, you should now know that five points of especial interest have been developed by the survey requested by a leading advertising agency. Because these 5 points are especially interesting to future advertisers in the Welding Journal, we thought we'd stack them up together to give you a chance to compare them with any magazine in the welding field to determine where you can get the most from the advertising dollar.

1

Read Welding Journal regularly . . . **98%**

Proof of complete liaison between the editorial staff and the reader

2

Find Journal contents helpful . . . **98%**

Proof that W.J. contents are **basic** to the whole welding profession

3

Read ads in Journal . . . **87%**

Proof that Welding Journal readers are ever-alert for new products

4

Have bought products as result of reading Welding Journal . . . **49%** (!)

Proof of effectiveness of Journal for advertising any welding product or service

5

Have investigated new processes on basis of ads in Journal . . . **71%**

Proof that W.J. readers are alert, curious, show-me kind of people . . . the kind who are proud of their profession and their contribution to industrial progress. Can you afford to miss this market?

WELDING JOURNAL

NEWS of the industry

Airco Appoints Brest

E. E. (Gene) Brest has been appointed general superintendent of the Pacific Coast plants of Air Reduction Pacific Co. replacing Frank Myers, deceased.

Brest, who had his early schooling in Pennsylvania and graduated from Carnegie Tech. in 1948, joined Airco at the Johnstown, Pa. plant that same year. He will make his headquarters at the company office in Berkeley, Calif.

Metal & Thermit Earnings and Sales Increase

Sales and earnings of Metal & Thermit Corp. during the three months ended June 30, 1959, continued the uptrend of the past twelve months, and the rate of gain of earnings is now outstripping that of sales.

Net sales during the June quarter amounted to $10,999,642, an increase of 31% over the $8,395,636 reported for the three months ended June 30, 1958. The June quarter sales represented a gain of 12% over the first quarter of this year.

Net earnings after income taxes during the three months ended June 30, 1959, amounted to $496,032. The earnings were equal to 61 cents per share on 792,550 common shares outstanding, after payment of preferred dividends, compared with 19 cents a year ago, an increase of 221% over a year ago.

Linde Promotes Dato

Linde Co., Division of Union Carbide Corp., has announced the appointment of J. E. Dato AWS as sales manager, electric welding. His previous assignment was manager—

J. E. Dato

HOGLUND VISITS HOBART WELDING SCHOOL

AWS Past-president G. O. Hoglund (center) discusses new welding developments with E. A. Hobart (left) and W. H. Hobart (right) during his recent visit to the Hobart Brothers Technical School.

COMING EVENTS

A Calendar of Welding Activity

AWS National Meetings

1959 National Fall Meeting: September 28–October 1. Sheraton-Cadillac Hotel, Detroit, Mich.

41st Annual Meeting and Eighth Welding Show: April 25–29, 1960. Biltmore Hotel, Los Angeles, Calif.

NWSA

October 19–20. West Central Zone Meeting, Pick-Nicolett Hotel, Minneapolis, Minn.

October 22–23. Western Zone Meeting, Riviera Hotel, Las Vegas, Nev.

ASM

November 2–6, 1959. 41st National Metal Exposition and Congress. International Amphitheatre, Chicago, Ill.

electric welding, Eastern Region. His association with the Linde Co. began with a field assignment in 1936. He has been active in the development and promotion of the inert-gas welding processes, and has held a number of positions in the American Welding Society.

A. O. Smith Uses Trailers for Sales

Industrial plants are now being given firsthand demonstrations of A. O. Smith Corp. CO_2 welding process by the firm's Welding Products Division salesmen through use of self-contained trailers.

Each trailer, which contains all of the equipment necessary to perform on-the-spot CO_2 welding, is easily pulled from plant to plant by the salesman's automobile. Demonstrations are made by appointment with key production personnel, with the salesman showing at the time of his plant call the applications of the process to particular joining problems.

Victor Expands Operations

The Welding Equipment Division of Victor Equipment Co., San Francisco, Calif. has been expanded on both an area and personnel basis.

E. O. Williams will now supervise the entire Southwestern District Sales Division and handle establishment of branch outlets in the district.

F. V. McGinley has been appointed branch manager in Los Angeles and assistant manager of the division.

Salvaging Aluminum

A total of more than 7 billion pounds of scrap aluminum has been salvaged, processed into alloys and returned to American industry for a wide variety of uses since 1948, according to the Aluminum Smelters Research Institute, Chicago.

The institute predicted that, through expanding knowledge of metallurgy, more than 15 billion pounds will be returned to the nation's aluminum users during the next 10 years.

Comparable to alloys made with primary aluminum, the smelters alloys are converted into castings for the automobile industry, appliance manufacturers, business machines and a host of other end-use products.

All-State Distributors

Recent appointments of new distributors for All-State Welding Alloys Co. include Seaboard Oxygen Service, Plymouth, N. C.; Welders Supply Co., Beloit, Wis.; and Kirk's Auto Electric Inc., Bowling Green, Ky. On the export side, All-State announces the appointment of Viotti y Cia of Buenos Aires, Argentina. All-State alloys and fluxes for welding, brazing and soldering can be obtained from these new distributors.

ASM Names New Officers

Walter Crafts, associate director, technology, Union Carbide Metals Co., has been named new president of the American Society for Metals.

Also picked by the society's nominating committee were a new vice president, a treasurer and two trustees.

The new officers will be formally elected at the annual meeting of the 30,000-member engineering society of the metalworking industry in Chicago on November 4th during the 41st National Metal Exposition and Congress. They will take office at the conclusion of the Metal Show, November 6th.

Nominated in addition to Crafts are William A. Pennington, professor of metallurgy, University of Maryland—vice president; Robert J. Raudebaugh, supervisor, iron-nickel alloys, International Nickel Co.—treasurer; Albert H. Fairchild, senior staff engineer, metallurgist, Western Electric Co.—trustee; and C. H. Samans, GMS associate director, engineering research, Standard Oil Company (Indiana)—trustee.

Emerson Electric Expands

The sales force of Emerson Electric welding machines has been substantially increased through new appointments of salesmen, agents and distributors.

The following are the new Emer-

NATIONAL CARBIDE
IN THE RED DRUM

HIGHEST QUALITY

DUST FREE

DEPENDABLE SUPPLY

Write for the name and address of the NATIONAL CARBIDE supplier nearest you.

National Carbide Company
A DIVISION OF AIR REDUCTION COMPANY, INCORPORATED
GENERAL OFFICES: 150 EAST 42ND STREET, NEW YORK 17, N. Y.
AT THE FRONTIERS OF PROGRESS YOU'LL FIND AN AIR REDUCTION PRODUCT
For details, circle No. 18 on Reader Information Card

son Electric sales appointees and the areas they will handle:

Richard C. Mundwiller—North Dakota, South Dakota, Nebraska, Minnesota, Iowa, Wisconsin, Michigan and Missouri; Sam N. Garber—California, Oregon, Washington, Montana, Idaho, Wyoming, Utah, Nevada, Arizona and New Mexico; Harold F. Flynn—Pennsylvania, Maryland, Delaware, New Jersey, New York, Connecticut and Massachusetts.

Nasco, Inc., located in Birmingham, Alabama and Ft. Worth, Texas, has been appointed an exclusive agent for Emerson products and will be represented by five salesmen (H. L. McElhoe, Ed Tucker, Joe L. Griffin, Jr., W. H. Fulton and E. M. Langston) in Colorado, Kansas, Oklahoma, Texas, Arkansas, Illinois, Louisiana, Virginia, Mississippi, Tennessee, Alabama, Georgia, Florida, South Carolina and North Carolina; McFarlane-Green, located in Winnipeg, Canada will cover western Canada (Province of Manitoba, Saskatchewan, Alberta and British Columbia) and will be represented by Garry McFarlane.

H. Kroh will represent the company in Hawaii, and W. D. Blood & Co. of New York, N. Y. has been appointed as the export welding-machine sales division.

O.K.I. Welding Supply Co. of Cincinnati, Ohio will distribute Emerson products in Ohio, Indiana, Kentucky and West Virginia.

Welding Supply House

Welders' Supply Co., distributor subsidiary of Chemetron Corp., has opened its tenth store in the Southern California area.

The new store is located at 13343 Sherman Way, North Hollywood, and is under the management of Bob Von Dulm. Welders' Supply Co. handles the industrial oxygen, acetylene, nitrogen, argon, helium and hydrogen, and a complete line of gas-welding, arc-welding, brazing and flame-cutting equipment.

Industrial Air Products Promotes Two

M. A. (Mike) Gudman and Kurt Kuhlmann have been promoted to vice presidencies of Industrial Air Products Co.

Gudman, whose title will now be vice president-comptroller, was formerly comptroller of IAP. He was previously treasurer-comptroller of White Stag for nearly four years and before that was with Columbia River Packers Association.

Kuhlmann, up to now general plant superintendant, will direct all IAP production. He was awarded a degree in physics by the Graduate Institute of Technology of Berlin in 1948 and later did further graduate study in the same field at Columbia University. He joined IAP from American Messer Co. of New York.

GE Relocates Resistance-welding Groups

General Electric is transferring its resistance-welding control business to Detroit, center of its heaviest customer concentration.

The company's Service Shops Department, through its Detroit operation at 5950 Third Ave., will engineer, manufacture and market all General Electric controls for resistance-welding applications and will handle renewal parts and repair.

Responsibility for advanced engineering of the line also is being transferred to Detroit. Sales and service will continue nation wide through all General Electric apparatus offices.

The business is being integrated into the custom engineering and manufacturing activity of the Detroit Service Shop. Already completed for much of the line, the relocation—from the company's Specialty Control Department, Waynesboro, Va.,—will be concluded by year's end.

New Oxygen Facilities

A new storage and distribution installation to supply gaseous oxygen for shape-cutting of steel was officially placed in operation recently at Earle M. Jorgensen Co.'s steel warehouse, 700 Pennsylvania Ave., San Francisco, Calif.

The installation is the first of its kind for industrial applications in San Francisco.

Look to Cayuga for the best
WELDING HEAD MANIPULATORS ...TURNING ROLLS
Cayuga Weldomatic Manipulators are built in a wide range of sizes and variety of models. Designed for automatic longitudinal welding, with ram and truck tank fabrication and for use with turn tables and positioners. Available with or without trucks.
OTHER PRODUCTS
Turn Tables
Positioners
Travel Carriages and Beams
Contour Welders
Horn Jigs
Sheet Splicers
Motor Stator & Transformer Core Welders
Tank Welders
Head & Tail Stocks
Wire Reels
Send for complete information
CAYUGA SUPER CHIEF
CAYUGA BIG CHIEF
TURNING ROLLS
1 to 100 ton, 6" and up diameter tank range. Rheostat remote speed control.
CAYUGA MACHINE & FABRICATING CO., INC.
Depew—Buffalo, New York
For details, circle No. 38 on Reader Information Card

Lower final costs with aluminum welding materials from ALCOA

Your Guide to the Best in Aluminum Value

ALCOA ALUMINUM

No matter how you join aluminum—by welding, soldering or brazing—you can lower the cost and improve the quality of your end product if you use materials from Alcoa. The reason: rigid quality controls and thorough testing that go into all Alcoa welding materials assure you of more sound welds and fewer rejects.

But, as a supplier, Alcoa does more than furnish first-quality materials. Alcoa also offers you the benefit of extensive research in alloys, welding techniques and joining methods. From design to production, this single source can work with you to answer any joining requirement, no matter how large or small.

Consider this complete line of welding materials from Alcoa:

WELDING FILLER METAL AND FLUX

IG (INERT GAS) WELDING ELECTRODE: For the consumable electrode, inert gas shielded metal arc welding process. Available in a wide variety of alloys, level wound on 10-lb and 1-lb spools.

COILED WELDING ROD: Available in standard mill-wrapped coils approximately 55 lb in weight. Etched or commercial finish; several alloys are available for immediate delivery, others fabricated on request.

STRAIGHT-LENGTH WELDING RODS: Thirty-six-inch straight-length welding rods, packed in 5-lb tubes; 10 tubes to a standard shipping carton. Other alloys and sizes fabricated on request.

WELDING FLUX: Available in jars of 8 oz, 1 lb, 5 lb; drums of 50 lb and 150 lb. General use is for oxyacetylene or oxhydrogen gas welding. No. 22 flux, colored deep pink to facilitate identification.

BRAZING SHEET, ROD AND FLUX

BRAZING SHEET: Made as a one- or two-sided clad product with the filler metal integrally bonded to a core alloy, or in the form of shim stock of a brazing filler alloy.

COILED BRAZING ROD: Standard wrapped coils with etched or commercial finish in sizes from ¼-in. to 1/16-in. types available for standard or specialized brazing operations.

STRAIGHT-LENGTH BRAZING RODS: Thirty-six-inch straight lengths packed in 5-lb tubes, 10 tubes to a standard carton. Sizes from ¼ in. to 1/16 in. May be applied either by flowing into the joint when torch brazing or as wire rings or other shapes when furnace or dip brazing.

BRAZING FLUX: Four types available, color coded for identification purposes. Available in packages ranging from 8-oz jars to 150-lb drums to fill any brazing requirement.

SOLDERING SHEET, SOLDER, SOLDERING FLUX

SHEET: Zinc-coated aluminum sheet, clad on either one or two sides. This new product permits easier joining and provides maximum resistance to corrosion.

SOLDER: Two types available for low- or high-temperature applications. Available in a variety of spool and stick sizes; high-temperature solder can be used to join aluminum with copper, brass, steel, stainless steel, nickel, etc.

SOLDERING FLUX: Several types available for use with both high- and low-temperature solder. Available in packages ranging from 1-oz bottle to 150-lb drum.

Any of the distributors listed can give you full information on aluminum welding and brazing processes. Also, a number of films are available from Alcoa on a loan basis. Further information is available from Aluminum Company of America, Pittsburgh 19, Pa.

For exciting drama watch "Alcoa Presents" every Tuesday, ABC-TV, and the Emmy Award winning "Alcoa Theatre" alternate Mondays, NBC-TV

For details, circle No. 19 on Reader Information Card

Want technical help in welding, brazing or soldering aluminum? Contact your Alcoa sales office, listed under "Aluminum" in the Yellow Pages of your phone book.

For immediate delivery of Alcoa welding products, call your Alcoa outlet listed below. He carries a complete range of alloys and sizes.

ALABAMA
Birmingham
Hinkle Supply Co.

CALIFORNIA
Los Angeles
Ducommun Metals & Supply Co.
Pacific Metals Company, Ltd.
San Francisco
Pacific Metals Company, Ltd.

COLORADO
Denver
Metal Goods Corp.

CONNECTICUT
Milford
Edgcomb Steel of New England, Inc.
Windsor
Whitehead Metals, Inc.

FLORIDA
Jacksonville
The J. M. Tull Metal & Supply Co., Inc.
Miami
The J. M. Tull Metal & Supply Co., Inc.
Tampa
The J. M. Tull Metal & Supply Co., Inc.

GEORGIA
Atlanta
The J. M. Tull Metal & Supply Co., Inc.
Mid-South Oxygen Co.

ILLINOIS
Chicago
Machinery & Welder Corp.
Steel Sales Corp.

KANSAS
Wichita
Metal Goods Corp.

KENTUCKY
Louisville
Williams and Co., Inc.

LOUISIANA
New Orleans
Metal Goods Corp.

MARYLAND
Baltimore
Southern Oxygen Co.
Whitehead Metals, Inc.
Bladensburg
Southern Oxygen Co.

MASSACHUSETTS
Cambridge
Whitehead Metals, Inc.

MICHIGAN
Detroit
Steel Sales Corp.

MISSOURI
Kansas City
Metal Goods Corp.
St. Louis
Metal Goods Corp.
Steel Sales Corp.

NEW HAMPSHIRE
Nashua
Edgcomb Steel of New England, Inc.

NEW JERSEY
Harrison
Whitehead Metals, Inc.

NEW YORK
Buffalo
Whitehead Metals, Inc.
New York
Whitehead Metals, Inc.
Syracuse
Brace-Mueller-Huntley, Inc.
Whitehead Metals, Inc.

NORTH CAROLINA
Greensboro
Southern Oxygen Co.

OHIO
Cincinnati
Williams and Co., Inc.
Cleveland
A. M. Castle & Co.
Williams and Co., Inc.
Columbus
Williams and Co., Inc.
Toledo
Williams and Co., Inc.

OKLAHOMA
Tulsa
Metal Goods Corp.

OREGON
Portland
Pacific Metal Co.
J. E. Haseltine & Co.

PENNSYLVANIA
Philadelphia
Edgcomb Steel Co.
Southern Oxygen Co.
Whitehead Metals, Inc.
Pittsburgh
Williams and Co., Inc.
York
Southern Oxygen Co.

TENNESSEE
Kingsport
Southern Oxygen Co.

TEXAS
Beaumont
Big Three Welding Equip. Co.
Corpus Christi
Big Three Welding Equip. Co.
Dallas
Metal Goods Corp.
Texas Welding Supply Co.
Houston
Metal Goods Corp.
Big Three Welding Equip. Co.
San Antonio
Big Three Welding Equip. Co.

UTAH
Salt Lake City
Pacific Metals Company, Ltd.

VIRGINIA
Norfolk
Southern Oxygen Co.
Richmond
Southern Oxygen Co.

WASHINGTON
Seattle
Pacific Metal Co.
J. E. Haseltine & Co.
Spokane
J. E. Haseltine & Co.

WISCONSIN
Milwaukee
Machinery & Welder Corp.
Steel Sales Corp.

ARCAIR GRADUATES

Graduates of Arcair's first class for distributor salesmen display their certificates. Seated (left to right) are Bob Coder, President Myron Stepath of Arcair and Manual Martinez. Standing are Jerry McEvilly of Arcair, Ed Boersma, Bob Sarter and Elmer Lehmkuhl, also of Arcair

Manufactured by Linde Co., Division of Union Carbide Corp., the unit consists of a vacuum-insulated tank which stores the gaseous equivalent of 25,000 cubic feet of oxygen at −300° F.

Sperry Products Announces Sales Reorganization

A newly expanded sales program for Sperry Products, Inc., has been announced. Four sales districts have been established, each of which will be supervised by a district manager.

The new district managers are: Tracy W. McFarlan, Eastern District, New York; Ralph H. Frank, Central District, Pittsburgh; James M. Dickey, Midwest District, St. Louis; and Carl B. Haugh, Western District, Los Angeles.

Sperry also announced the appointment of George Campbell as marketing research coordinator.

FOR WORK IN A CONTROLLED ATMOSPHERE

BLICKMAN
VACUUM DRY BOX

Designs and specifications are available for a variety of welding enclosures for research and production welding, and for work in the fields of metallurgy and physical chemistry. These enclosures can be fully evacuated and then be filled with an inert gas for welding in an inert atmosphere. Write for Technical Bulletins on various types of welding enclosures: S. Blickman, Inc., 3010 Gregory Avenue, Weehawken, N. J.

BLICKMAN
LABORATORY EQUIPMENT

Look for this symbol of quality Blickman-Built

For details, circle No. 16 on Reader Information Card

Emerson Electric Expands Division

Emerson Electric of St. Louis announces expansion of all engineering activities in its electrical division in order to intensify research on product development and customer requirements.

DYE OXYGEN EXPANDS FACILITIES

Shown above is the completion of the first phase of Dye Oxygen Co.'s two-year expansion program. This program includes a new loading dock complete with servicing facilities, as well as a new dry ice and CO_2 department. The second phase of the expansion program will include construction of a $33,000 executive and general office building. The third part of the two-year plan will be the construction in Phoenix, Ariz., of a 17-ton liquid-oxygen plant. This last unit was completed July 1959 at a cost of $850,000

IN OUR 20th YEAR OF

R. D. WASSERMAN
President

R. F. FOX
National Sales Manager

NEW SALES MANAGEMENT TEAM

...and some of the three-hundred-fifty Regional Managers and Technical Representatives who spearhead the world renowned Eutectic organization.

F. W. GLASER
Treasurer-Controller

DONN BORING
Advertising Manager

J. F. QUAAS
Vice-President of Research and Manufacturing

R. H. GROMAN
Director of Applied Welding Engineering

J. P. BRODERICK
Supervisor, Technical Service Department

S. A. JOHNSON
Sales Administration

For details, circle No. 20 on Reader Information Card

PROGRESS AND SERVICE

To the Welding Industry...

EUTECTIC PEOPLE MAKE THE BIG DIFFERENCE

Eutectic Welding Alloys Corporation is entering its third decade of service to industry . . . service based on the finest products known to welding science . . . service based on the experience and knowledge of more than a thousand men devoted to solving the problems of the metal joining industry.

With a background of 50 years of research and development, and in its 20th year as a world-wide organization, EUTECTIC produces more than one-hundred-sixty "Low Temperature Welding Alloys"® and Fluxes, compounded on the original Low Heat Input process developed by EUTECTIC.

Specialists? Yes, From creative founders to progressive management, scientists, engineers, technicians, metallurgists, skilled factory craftsmen, and 350 specially trained Technical Representatives in the field, Eutectic Welding Alloys Corporation is an army of specialists. Specialists in helping users of EUTECTIC products to utilize the most modern welding alloys and aids known today . . . products that save time and money, minimize warpage, distortion, and weld embrittlement through Low Heat Input, and assure consistently successful results.

® REGISTERED TRADE MARK OF :

©1959 EWAC

EUTECTIC WELDING ALLOYS CORPORATION

40-40 172nd St., FLUSHING 58, NEW YORK

Warehouses and Service Centers in ATLANTA; BOSTON; CHICAGO; COLUMBUS, OHIO; DALLAS; DETROIT; LOS ANGELES; ST. LOUIS; SEATTLE; BERKELEY, CALIF.; HURON, SD. DAKOTA; PHOENIX, ARIZONA.

Canadian Plant and Headquarters: Montreal
Warehouses: Dartmouth, N. S., Toronto and Vancouver

For details, circle No. 20 on Reader Information Card

PERSONNEL

Roediger, Jones Promoted by Hobart Brothers Co.

Robert E. Roediger AWS has been named manager of electrode sales for Hobart Brothers Co., Troy, Ohio. He was formerly district representative in the southeastern states.

Wendell Jones AWS was appointed as district representative for the south central states of Tennessee, Alabama, Mississippi and Louisiana to succeed Roediger.

Mr. Jones was formerly district manager for Welding Gas Products Co., Chattanooga, Tennessee.

Canadian Field Representative

Donn Fraser has recently been appointed field representative in Canada by the Arcair Co., Eastern Division, Lancaster, Ohio. He will call on and work with Arcair Distributors in all provinces of Canada with the exception of British Columbia.

Mr. Fraser's background has long been connected with the welding industry in its practical applications and as an instructor, both in Canada and in South America. He has worked for a short period in the United States.

Fox Appointed by Eutectic

The appointment of Robert F. Fox AWS to the position of national sales manager was made recently by Eutectic Welding Alloys Corp.

Mr. Fox brings to his new position an impressive background in the welding industry and has been with the company for the past 13 years. He has served as district engineer and also as regional manager for the Metropolitan New York-New Jersey area.

Gill, Christoffel Promoted by G.E.

The Materials and Processes Laboratory of the General Electric Co.'s Large Steam Turbine-Generator Department has appointed two new supervisors.

Robert F. Gill's new assignment will be in the field of castings and mill products and Robert J. Christoffel's duties will be in arc and gas welding.

Mr. Gill is a member of the American Society of Metals and the Edison Club.

Mr. Christoffel, AWS, is a graduate of Rensselaer Polytechnic Institute, and a member of the American Society of Metals.

Happ Joins Tang Industries

Tang Industries of Waltham, Mass., manufacturer of semiconductor materials and electronic components, announces the appointment of Marvin B. Happ, former chief metallurgist with the Walworth Co., and a member of the Boston Chapter, AWS, as assistant general manager.

Mr. Happ has an extensively rounded background in the metallurgical research, development and application fields, including product quality and cost control, and is active in various national technical societies.

Castor Named by Linde Co.

C. R. Castor has been appointed sales manager for Crystal Products by Linde Co., Division of Union Carbide Corp., effective September 1st. He will make his headquarters in the Crystal Products plant at East Chicago, Ind.

Linde has been for many years a producer of synthetic crystals for a variety of uses in both the mechanical and electronic areas. In addition, the company also produces synthetic star sapphires and star rubies in large and small sizes for the jewelry trade.

A native of Parrottsville, Tenn., Dr. Castor received a degree in chemistry from Baylor University, and did graduate work at Duke University.

Halladay Appointed by Budd Co.

The appointment of Richard S. Halladay as Sales Engineer, Nuclear Systems, a Division of the Budd Co., was announced recently.

Prior to joining Budd, Mr. Halladay was a sales engineer for eight years with Aluminum Industries, Cincinnati, Ohio.

Mr. Halladay is a native of Galesburg, Ill. and was graduated from Bradley University with a B.S. in Mechanical Engineering.

Cline Added to Oak Ridge Staff

Mr. Cecil L. Cline, from the Ohio State University, has recently been appointed to the staff of the Oak Ridge Y-12 Plant. This is an Atomic Energy Installation operated by Union Carbide Nuclear Co., a division of Union Carbide Corp.

Duncan Named to Sales Post

The Sight Feed Generator Co., West Alexandria, Ohio, has an-

R. E. Roediger

Wendell Jones

Robert F. Fox

nounced the promotion of C. Blaine Duncan to the position of general sales manager. The promotion was made effective July 27th.

Mr. Duncan will direct the total sales program, domestic and export, for the firm, and correlate the advertising and sales promotion activities with the sales program.

EMPLOYMENT SERVICE BULLETIN

Positions Vacant

National manufacturer with unique stud welding process needs an Applications-Sales Engineer with welding and sales experience—engineering experience desirable. Responsible for sales planning—training programs—special application development. Rapid promotion; salary open; to be located in Cincinnati. Contact Guy E. Sabin, OMARK Industries, Inc., 9701 S. E. McLoughlin Blvd., Portland, Oregon.

V-380. Publicity assistant reporting to vice president and general manager. Background: engineering-metallurgical; writer; publicity; young and bright. Wages: open. Duties: Responsible for collecting information, writing and placing (selling) application stories and news releases with appropriate publications. Responsible for certain market research activity. Also for writing technical data sheets, catalogs, speeches, house organs, promotional letters and pieces. Schedule publicity promotion campaigns for new products as well as existing products, and other details required of a well-run Publicity department.

WANTED

PRODUCTION ENGINEER

EDUCATION: BSME, BSMET. E.; MSME, MSMET.E.

EXPERIENCE DESIRED: Practical background in resistance and inert gas welding.

DESCRIPTION OF DUTIES: Advise design approach and develop tools and methods for miniature and sub- assemblies on a production basis; develop methods for welding, brazing and other similar methods of joining new and different materials.

Send your résumé to or contact Mr. M. Nelson, Personnel Dept. 546.

MICRO SWITCH
a division of Honeywell
Freeport, Illinois

OBITUARY

John H. Mulder

John H. Mulder AWS, former secretary of Miller Electric Mfg. Co., Inc., and member of the board of directors, passed away at his home in Appleton, Wis., on Sunday, August 2nd. He had retired from the firm last March.

John H. Mulder

Engaged since 1912 in some branch of the electric industry, Mulder met Niels C. Miller in 1929, in which year Miller Electric Mfg. Co. was incorporated with Mulder as secretary.

Albert F. Wall

Albert F. Wall, chairman of the board of Wall Colmonoy Corp., producer of hard-surfacing alloys and brazing materials for industry, died at the age of 68 on Aug. 3, 1959 in Detroit, Mich., where he had lived since 1920.

Born in Montreal, Mr. Wall received his engineering degree from McGill University. He was founder and president of several manufacturing firms and was well known in sporting circles as owner of a thoroughbred horse-raising farm near Lexington, Ky.

In addition to his position as Wall Colmonoy board chairman, Mr. Wall was also president of both Wall Colmonoy (Canada) Ltd., Montreal East, Quebec, and Wall Gases. He successively founded Wall Brothers, Wall Brothers Oxygen Co., Diamonds and Tools, Inc., and Wall Chemicals which was sold in 1939 to Liquid Carbonic, Inc.

RESISTANCE WELDING ENGINEER

Challenging position for qualified engineer to develop resistance welding techniques, perform experimental weld analyses on advanced welding equipment, and assist in difficult customer applications of resistance welding.

Must have engineering degree and minimum of five years experience with resistance welding.

Outstanding opportunity with the fastest growing company in the resistance welding field. Weldmatic produces a full line of stored-energy welding equipment for precision resistance welding.

Write, outlining qualifications and experience to:

Personnel Section

WELDMATIC

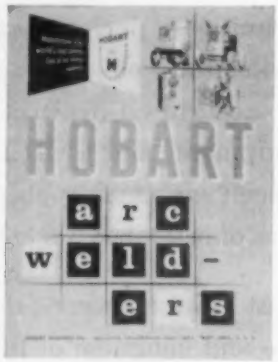
DIVISION OF UNITEK CORPORATION
380 NORTH HALSTEAD AVENUE
PASADENA, CALIFORNIA

New Literature

Welding-equipment Catalog

Hobart arc welding machines are described and illustrated in a new 24-page, 2-color catalog available from Hobart Brothers Co., Troy, Ohio.

This comprehensive catalog includes complete specifications and ordering information on gasoline- and diesel-engine-driven welding machines, electric-motor-driven arc



welding machines, rectifier-type welding machines, transformer-type welding machines, combination transformer-rectifier-type welding machines, a-c and d-c inert-gas-shielded arc welding machines and a complete line of automatic and semi-automatic welding equipment.

In addition to covering welding equipment, the catalog also describes a line of induction-heating equipment, pipe-thawing equipment and a power source for cutting and gouging.

For your free copy, circle No. 51 on Reader Information Card.

Shape-cutting Machine

A fully illustrated 8-page booklet now available from Linde Co., Division of Union Carbide Corp., 420 Lexington Ave., New York 17, N. Y. describes the Oxweld CM-60 said to be the world's first unlimited capacity shape-cutting machine that can automatically reproduce metal parts from exact-size drawings. Oxyacetylene cutting torches of the CM-60 follow electronic impulses from the Linde Photocell Tracer. Intricate parts are produced by feeding exact size drawings of the part into the photoelectric tracing system. All cutting operations are controlled by a single operator sitting at a convenient control panel.

For your free copy, circle No. 52 on Reader Information Card.

Aluminum-clad Copper

A new 4-page technical booklet, "Aluminum-clad Copper 40%," made available by Sylvania Electric Products Inc., describes a high-conductivity wire recently developed by the company for high-temperature magnet wire and a variety of applications in aircraft, missiles and high-speed industrial equipment. Sylvania is a subsidiary of General Telephone & Electronics Corp.

The new Sylvania wire is said to combine the high-conductivity advantages of copper with the high-temperature properties of aluminum. The cladding, an aluminum alloy, equals a cross-sectional area of approximately 40% of the composite wire.

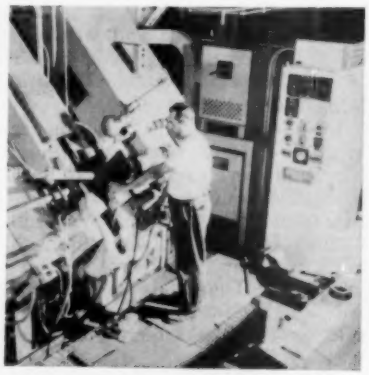
For your free copy, circle No. 53 on Reader Information Card.

Resistance Welding

Sciaky Bros., Inc., 4915 W. 67th St., Chicago, Ill., announce a new Vol. 5, No. 5 of their "Resistance Welding at Work" house organ publication.

This 16-page bulletin is the fourth of a series which fully describes a variety of resistance welding case histories. Both high-standard aviation and commercial welding are included. Many production advantages, and the betterment of product quality have been obtained in each of these instances through Sciaky resistance welding and techniques.

For your free copy, circle No. 54 on Reader Information Card.



Flash-butt welding of the Douglas F4D-1 (Skyhawk) arresting hook

Horn Presses

A 12-page color bulletin No. 42710A, published by The Federal Machine and Welder Co., Warren, Ohio, illustrates and describes the Warco line of horn presses in capacities from 50 to 200 tons inclusive.

For your free copy, circle No. 55 on Reader Information Card.

Structural Aluminum

A new edition of "Alcoa Structural Handbook" is available in limited quantity from Aluminum Company of America, 789 Alcoa Bldg., Pittsburgh 19, Pa.

The 420-page book, including 140 tables, supplies design information on the use of aluminum in structures. New material includes updated and new tables, data on aluminum-magnesium alloys and coverage of welded structure design.

For your free copy, circle No. 56 on Reader Information Card.

Vinyl-coated Steel

Applications of vinyl-coated steel sheet are described in a brochure available from United States Steel Corp., 525 William Penn Place, Pittsburgh 30, Pa. Various consumer products using this versatile material are described.

For your free copy, circle No. 57 on Reader Information Card.

Compressed-air Fundamentals

Ingersoll-Rand Co., 11 Broadway, New York 4, N. Y., has just published a new booklet entitled, "Compressed Air Fundamentals." This literature was produced to help in the selection of small "packaged" air compressors for either automotive or industrial applica tion. The book also describes compressed air, how it is compressed, single- and two-stage compressors, piston displacement, actual delivery, unloading of compressors, regulation and types of control used. Other material included is information on compressor oils, pipe sizes, wire sizes and terminology and definitions used in connection with the compression of air.

For your free copy, circle No. 58 on Reader Information Card.

Carbon-dioxide Welding

serts that these new products assure

Also included is information on

Tempilstik°. . . temperature indicating crayons

TEMPILSTIKS° provide a simple and accurate means of determining preheating and stress relieving temperatures in welding operations. Tempilstiks° are widely used as a standard method of checking temperatures in all heat treating—as well as in hundreds of other heat-dependent processes in industry. Available in 80 different temperature ratings . . . . . $2.00 each.

Most leading welding supply houses carry Tempilstiks°. If yours is an exception, then write direct to us for further information.

Tempil° CORPORATION • 132 West 22nd St., New York 11, N. Y.

Visit our booth 225—National Metal Exposition—Chicago—Nov. 2–6.

For details, circle No. 5 on Reader Information Card

Carbon-dioxide Welding

The story of automatic and semiautomatic CO_2-shielded welding processes is told in a new brochure, "Who's Who in CO_2," prepared by the Welding Products Division, A. O. Smith Corp., Milwaukee, Wis.

The unique, 16-page brochure completely details A. O. Smith's three CO_2 welding processes. Illustrated charts outline typical CO_2 applications and detail wire diameters, amperages, voltages, travel speeds, weld positions and deposition rates. Two pages point out typical physical and mechanical properties that result.

For your free copy, circle No. 59 on Reader Information Card.

Brazing-flux Applicators

A new 4-page brochure on the new Rexarc Twin Liquifluxers and Liquiflux, new products of the Sight Feed Generator Co., West Alexandria, Ohio, is available without charge.

The new brochure is designed to answer most questions regarding the varied applications in the brazing process. The manufacturer asserts that these new products assure high quality and maximum production economies.

For your free copy, circle No. 60 on Reader Information Card.

Welding Controls

A new bulletin "Programmed Time-Amperage Control for Critical Welding" is offered by Harnischfeger Corp., Milwaukee, Wis. It describes five units for the sequence timing of welds, including motorized rheostat controls and punched-tape programming.

For your free copy, circle No. 61 on Reader Information Card.

Manifolds for Gases

A revised 24-page catalog, ADC 636E, describing the entire line of Airco manifolds for industrial gases is now available from Air Reduction Sales Co., a Division of Air Reduction Co. Inc., 150 E. 42nd St., New York 17, N. Y.

This new catalog contains illustrated information on capacities, dimensions and arrangement, along with general background material on the advantages of manifolding.

Also included is information on recently developed manifolds for CO_2, and liquid oxygen, argon and nitrogen, as well as current data on the standard manifolds for gaseous oxygen, argon, nitrogen, helium, acetylene, hydrogen and propane.

For your free copy, circle No. 62 on Reader Information Card.

Stud Welding

More than a dozen varied stud-welding applications, which reportedly have enabled manufacturers to reduce their fastening costs anywhere from 30 to 60 percent, are shown in a 12-page booklet on "Reversing the Trend in Production Costs."

Published by Nelson Stud Welding, Division of Gregory Industries, Inc., Lorain, Ohio, the booklet includes a cost reduction work sheet to enable the reader to compute savings obtainable by Nelson Stud Welding on specific fastening operations. Examples range from giant wind tunnel compressor stators to small power tools and air-conditioning equipment.

For your free copy, circle No. 63 on Reader Information Card.

Fire-resistant Construction

A 44-page booklet discussing methods of fire protecting steel has been published by the American Institute of Steel Construction, 101 Park Ave., New York 17, N. Y. Titled "Fire-Resistant Construction in Modern Steel-framed Buildings," the booklet presents for easy reference the significant features of the fire-protective materials and fire-resistant systems that make steel-framed buildings economically competitive as well as structurally fire-safe.

During the past two decades, many fire-resistant light-weight floor and roof systems have been developed for use with steel construction. Believing that a compilation of these systems and their fire-resistance ratings would be helpful, the AISC, national organization representing the structural steel fabricating industry, has prepared the booklet specifically as an aid to architects and engineers.

Included in the booklet are sections on modern building codes; the characteristics of fireproofing materials; the concept of "light-frame" fire-resistant steel construction; and a reference table showing more than 150 fire-resistant constructions and their fire-resistance ratings.

For your free copy, circle No. 64 on Reader Information Card.

SOLDERING PROBLEM?

stainless to aluminum?
aluminum to copper?
cast iron to steel?

BOEING 707 Landing Gear Harness Braided stainless steel wire and flexible conduit had to be joined to cast fittings. Brazing burned the fine wire. ALL-STATE had a special solder which solved the problem. (See #430, below.)

You get high strength with ALL-STATE special solders

#7 Special solder for cast iron 450-600°F. Withstands 1000 psi P.

#37 Developed for joining aluminum with soldering iron at low 450°F. Good color match and corrosion resistance. Also joins dissimilar metals. 1000 psi P.

#39 Special solder to join all types of aluminum for both build-up (450°F) and capillary flow (650°F) – with or without flux. 8000 psi T.

#55 Newly developed aluminum "rubbon"® solder – NO FLUX – 705°F – 20,000 psi T. All aluminums.

#105 Special medium temperature alloy for both ferrous and non-ferrous metals (640-740°F) – to 25,000 psi T.

#107 The finest made to join aluminum to steel, copper and brass – or to each other (480-600°F) – to 25,000 psi T.

#430 NO LEAD, NO ZINC or CADMIUM – develops tensile strengths of 10,000 to 28,000 psi on stainless and dissimilar metals. For soldering iron at a low 430°F.

Send for ALL-STATE Instruction Manual. ®RUBBON is a registered trade name.

Distributor-Stocked, convenient to buy. Economical to use.
ALL-STATE WELDING ALLOYS CO., INC., White Plains, N. Y.
Call WHite Plains 8-4646 or write for nearest distributor

For details, circle No. 21 on Reader Information Card

Medium Frequency (1200 TO 12,000 CYCLES) Induction Heating Equipment for Stress Relieving

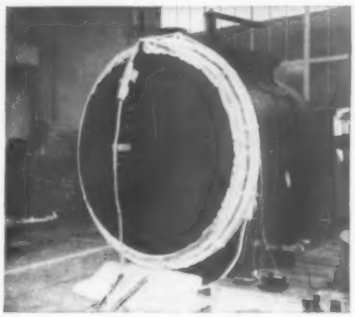
By Werner K. Haessler, Project Engineer, Brown Boveri Corp.

BROWN BOVERI

Brown Boveri manufactures turbine and generator shafts, precision marine gears and other products requiring flawless, stress-free weldments. After thorough testing, the Company adopted medium-frequency induction heating for stress relieving of weldments and for shrink fitting. Compact, mobile power-converters and special heat-resistant, insulated cable were developed . . . adding speed and flexibility to induction heating techniques. Standard sets are now available.

Advantages

Induction heating offers complete mobility not possible with furnaces. Even assembly welds at a customer's plant can be heat-treated. It generates the heat *inside* the metal as compared to furnaces or resistance heaters that heat from the *outside* using high surface temperatures. Thermocouple control allows more accurate adherence to prescribed temperature gradients. Simple cable and insulation arrangements cut labor cost. Cables and work can be covered with asbestos blankets to minimize radiation losses.



Cable arrangement for stress relief treatment of welded flange. Diam. 80", thickness ⅝", max. temp. 1148°F. Maximum power: 60 kw at 2.4 kc/s.

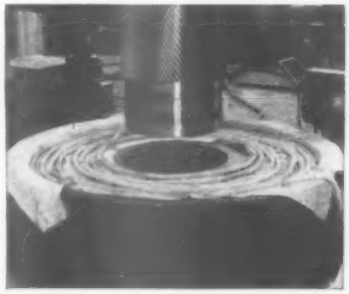
Medium frequency induction heating allows the use of relatively short and light cables with longer cable life. Since only a few turns are required, the energy is concentrated at the welding area allowing substantial power savings. The medium frequency system is adaptable for workpieces from 1/32" thick up to heavy forgings. (Low frequency systems, 50 to 400 cycles, require thick or very long cables and are limited to heating thick, heavy sections.)

Mobile truck for 38 to 110 kw output units. Larger units are also on a mobile chassis. Automatic temperature sequence control. Graph shows record of complete sequence.

Brown Boveri medium frequency converter sets

Frequency kc/s	Power kw	Voltage v	Input* kva
1.2	60	360	90
1.2	110	630	155
1.2	165	720	230
1.2	220	900	300
2.4	50	400	72
2.4	66	540	95
2.4	88	720	127
2.4	130	720	190
2.4	185	900	260
4.8	38	600	60
4.8	55	800	83
4.8	77	540	115
12	44	650	65
12	66	450	95

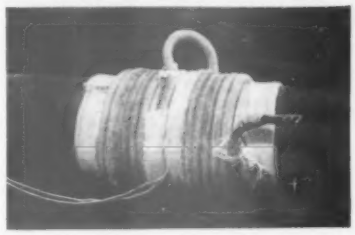
*3-phase motor input at 220, 440 or 500v, 60c.



Shrinking a gear wheel onto a shaft. The insulating blanket covering the cable has been removed to show the cable arrangement.

All sets are complete on a mobile, 4-wheel chassis. Plug and socket connections are supplied for connecting 2 similar sets in parallel for higher power. Drip-proof housing for outdoor exposure. Power and heat controls provide accurate, automatic heating, soaking and cooling periods with no supervision.

The complete range of Brown Boveri stress relieving units makes it possible to provide the frequency best suited for the specific size, thickness, composition and shape of the workpieces to be treated. In general, the lighter the workpiece, the higher the frequency. Experience has proved, however, that if one machine is to be used for a variety of applications, frequencies in the range of 2 to 2.5 kc are the most suitable.



Upper photo: Cable position during pre-heating at 850°F and welding. Below: Cable windings are simply pushed together and are ready for stress relief treatment up to 1250°F.

Brown Boveri Induction Cable

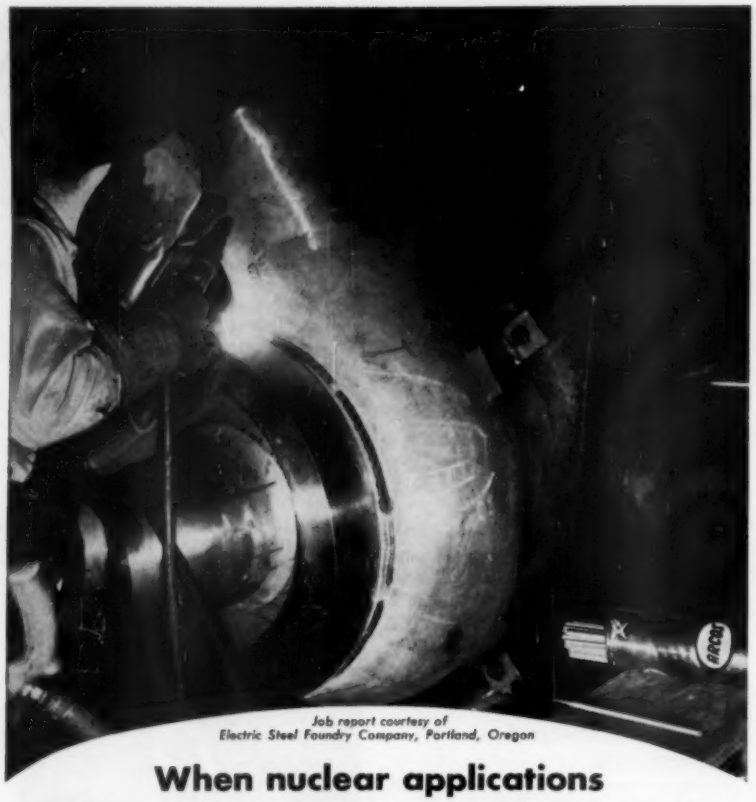
Highly flexible, heat-resistant. For work temperatures up to 1250°F without water cooling. Can be used for preheating then stress relieving without removal during welding. Bends to radii of 2" or less for easy application to the work. Supplied in easy-to-handle sections of 15 to 50 ft. quickly connected during application. Insulated for 1000v.

Write for complete details and Cost Estimate Questionnaire.

BROWN BOVERI

U. S. Sales and Engineering: Brown Boveri Corp., Dept WJ10, 19 Rector Street, New York 6, N. Y. Agents in 27 U. S. cities.

For details, circle No. 22 on Reader Information Card



Job report courtesy of
Electric Steel Foundry Company, Portland, Oregon

When nuclear applications call for stainless welds of highest quality

WELD WITH ARCOS

STAINLESS ELECTRODES

This is part of a 3900 lb. stainless pump-volute casting for a submarine nuclear power plant. In the photo, a skirt is being welded to the casting using 5/32" dia. Arcos Chromend K Electrodes. To minimize stresses, a step-back and skip procedure was used. These welds conformed to Class I Navy radiographic standards—an indication of the dependability of standard Arcos electrodes for your stainless welding needs. ARCOS CORPORATION, 1500 South 50th St., Philadelphia 43, Pa.

For details, circle No. 23 on Reader Information Card

Industrial Radiography

The steady growth of the industrial radiographic field is clearly demonstrated by the increase in references in the technical literature. The St. John X-Ray Laboratory, Clifton, N. J. announces availability of their latest *Bibliography on Industrial Radiography, 1956–1958*, priced at $4.00, with over 800 references and supplementing previous volumes. Earlier bibliographies containing some 4000 references are also available.

For details, circle No. 65 on Reader Information Card.

Grinding Wheels

"Built-in Guard" safety cup wheels for portable grinding in steel mills, foundries and welding shops are the subject of a new 2-color folder from Carborundum Co., Niagara Falls, N. Y.

How they are made, their advanced features, specifications, recommendations and how-to-order information is contained in this 5-hole punched folder—ready for purchasing and engineering manuals.

For your free copy, circle No. 66 on Reader Information Card.

Stainless Tubular Products

Engineers, purchasing agents and others involved in use of stainless tubular products in high-temperature applications will be interested in a new data card, TDC-195, published by the Tubular Products Division of the Babcock & Wilcox Co., Beaver Falls, Pa. This card describes the properties of B&W Croloy 25–20 (TP310)—its chemical composition, size ranges and short-time high-temperature tensile and rupture properties.

For your free copy, circle No. 67 on Reader Information Card.

Welding-power Sources

Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y. has recently made available reprints of an article on arc welding-power sources entitled "Which Welding-power Source Should You Use?"

This 8-page article was authored by C. A. McClean, Airco process engineer. It offers a comprehensive guide to the proper selection of arc welders for use with the stick electrode, gas-shielded tungsten-arc or gas-shielded metal-arc welding processes.

Illustrated with 14 schematic drawings, the article details eight

specific steps to be taken into account when choosing one of the four basic types of power sources: (1) location of the operation, (2) job and process requirements, (3) type of current, (4) machine characteristics, (5) auxiliary devices in the power source, (6) welding power, (7) welding duty cycle, and (8) shop power-supply voltage.

For your free copy, circle No. 68 on Reader Information Card.

Carbon-dioxide Welding

Just published by Hobart Brothers Co., Troy, Ohio, is a 38-page booklet on metal-arc welding of mild steel and low-alloy steels with carbon-dioxide shielding gas. The booklet describes carbon-dioxide welding and provides comprehen-

sive information on equipment and power sources, welding costs, deposition rates, welding preparation and positioning, electrode wires, weld-metal properties, test specimens, welding factors, tables and charts and many other factors that will give readers a good working knowledge of the technical as well as the practical aspects of CO_2 welding. Applications for a wide variety of industries are illustrated.

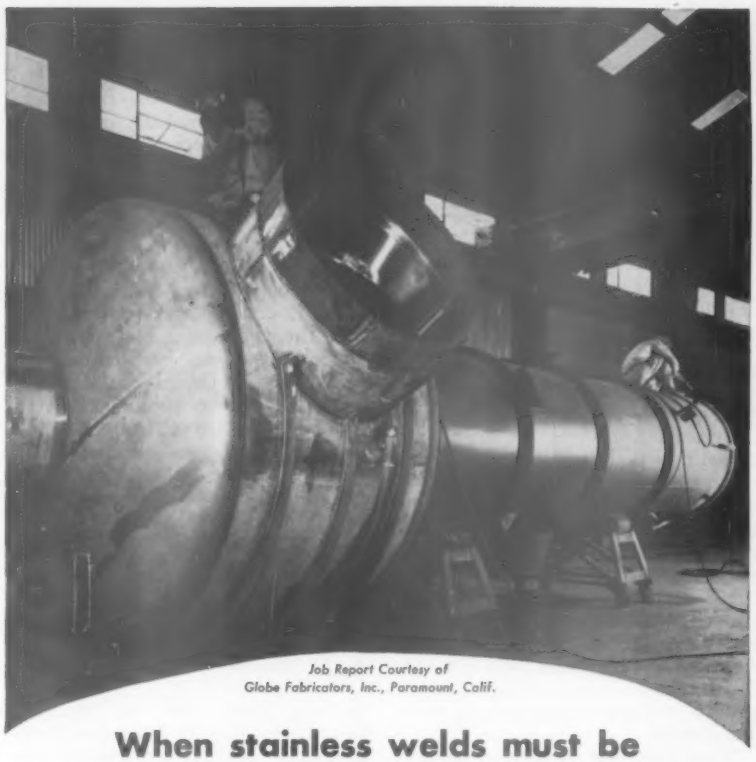
For your free copy, circle No. 70 on Reader Information Card.

Arc-welding Machines

An illustrated, 4-page brochure available from Mid-States Welder Co., 6025 South Ashland Ave., Chicago 36, Ill. describes the new line of Magna-Tran welding machines.

These welding machines are available in a-c and a-c, d-c versions and feature "plug-in" controls and timers. The arc designed for use with gas-shielded metal-arc or tungsten arc welding as well as standard electrode welding by manual or automatic means.

For your free copy, circle No. 69 on Reader Information Card.



Job Report Courtesy of
Globe Fabricators, Inc., Paramount, Calif.

When stainless welds must be highly sanitary and corrosion resistant

WELD WITH ARCOS

STAINLESS ELECTRODES

Welded citrus fruit processing equipment such as this must *resist corrosion*, must *not contaminate* the food and must be *strong*. Type 304 stainless, used for all food contacting sections, was welded with Arcos Chromend K (Type 308) electrodes. For welding the non-stainless supporting members to stainless sections, Arcos Chromend HCN (Type 310) electrodes were used. Again, Arcos electrodes provided multiple benefits that cost so little and contribute so much to dependable equipment operation. ARCOS CORPORATION, 1500 South 50th Street, Philadelphia 43, Pa.

For details, circle No. 24 on Reader Information Card

OF NEW BOOKS

Engineering Metallurgy

Basic Engineering Metallurgy, by Carl A. Keyser, University of Massachusetts. Revised Second Edition, 507 pages, 6- x 9-in. hard bound book. Price $8.50. Published by Prentice-Hall, Inc., Englewood Cliffs, N. J.

An up-to-date revision of the popular reference test, this edition retains the general organization of the first edition but accents a more scientific fundamental approach. In addition to new material on radiation effects, X-ray diffraction, new alloys, etc., many illustrations, line drawings, photographs and photomicrographs have been added.

The first six chapters discuss theoretical concepts and principles. Chapters 7, 8 and 9 are devoted to properties and heat treatment of steel. Chapters 10, 11 and 12 discuss nonferrous metals, while the remaining parts of the book deal with fabrication, plating, joining and finishing. A chapter dealing with welding is also included.

Welding Safety

Safety in Welding and Cutting. By A. N. Kugler, Air Reduction Sales Co. 92 pages, 5 x 7½ in., paper bound. This text is part of the International Correspondence School's welding curriculum and cannot be obtained without the instruction service provided by ICS.

This book covers the various aspects of safety as they apply to welding. Safety rules, safety with gas and electric arc processes, fire prevention, safety equipment, ventilation and health protection are discussed.

Fundamentals of Welding

Fundamentals of Welding. By A. N. Kugler, Air Reduction Sales Co. 95 pages, 5 x 7½ in., paper bound. This text is part of the International Correspondence School's welding curriculum and cannot be obtained without the instruction service provided by ICS.

An elementary, but thorough, text designed for home study, this book includes definitions of welding processes, joints and symbols as well as descriptions of welding techniques. Numerous drawings and diagrams help make the content clear and easily understood.

Radiation Effects

The Effect of Radiation on Materials—Vol. III—STP 233. 168 pages, hard cover, 6 x 9 in. Price $4.25. Published by the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

This volume is the third of a series of publications containing papers presented at symposia sponsored by ASTM and the Atomic Industrial Forum.

This third symposium is divided into three parts. The first deals with dosimetry techniques; the second with radiation facilities and techniques; and the third with radiation effects. All the information in this symposium is based on new data. This book should prove invaluable to all concerned with nuclear power, radiation shielding or the design and construction of nuclear facilities.

Among the papers are: "Dosimetry Techniques for Gamma and Reactor Radiation Fields," Paul Schall and J. F. Kircher; "Irradiation Facilities in NRU," G. C. Laurence; "The Engineering Test Reactor as an Irradiation Facility," R. L. Doan; "An Integrated Facility for Study of Effects on Nuclear Radiation on Materials," J. L. Colp and A. W. Snyder; "An In-Pile Fatigue Testing Apparatus," E. E. Drucker; "Reactor Pressure Vessel Design for Nuclear Applications," N. Balai, T. L. Kettles and R. E. Bailey; "Effects of Irradiation on the Type 347 Stainless Steel Flow Separator in the EBR-1 Core," R. E. Bailey and M. A. Silliman; "Radiation Damage Effects on Reactor Control Materials," W. E. Ray, W. K. Anderson and D. N. Dunning; Radiation Behavior of Fuel Materials for Sodium Graphite Reactors," B. R. Hayward, L. E. Wilkinson and C. C. Woolsey; "Irradiation of Uranium-Fission Alloys and Related Compositions," Karl F. Smith; "Effects of Nuclear Radiation on Natural Quartz Piezoelectric Crystals: Preliminary Investigation," F. E. Graham and A. F. Donovan; and "Effects of High Neutron and Gamma Fluxes on Transmission Characteristics of Some Optical Glasses," J. L. Colp and H. N. Woodall.

SOLID

SEMI-AUTOMATIC WIRE

New MANGANAL®

11% - 13½% MANGANESE - NICKEL STEEL

SOLID SEMI-AUTOMATIC WIRE

1. Higher deposition rate. (12 lbs./hr. on high amperage)
2. Higher build-up.
3. Cannot kink and crush in feed rolls.
4. Practically no spatter.
5. 25 lb. coils, 7/64" diameter.

NEAREST DISTRIBUTOR UPON REQUEST

SEE YOUR MANGANAL® DISTRIBUTOR

MEMBER

SOLE PRODUCERS

STULZ-SICKLES CO.

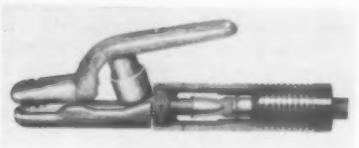
929 JULIA ST. • ELIZABETH, N. J.

For details, circle No. 23 on Reader Information Card

New Products

Electrode Holder

A completely new mechanical cable connection is featured in the new arc-welding electrode holders, Series ST (for Sealed Tight) placed on the market by Jackson Products, 31739 Mound Rd., Warren, Mich. Tongs are of heat-treated 98% copper alloy.



This cable connection is said to be quickly made and to allow no strain on the cable strands, nor peel-back of the cable jacket through flexure or tension, and will last the lifetime of either copper or aluminum cable.

The lower tong is threaded to receive a connection nut and terminates in a silver-plated point. When the nut is tightened, the stripped cable strands are spread equally and smoothly around this point, sealed tight against moisture and dirt.

The connection nut extends to form a ferrule around the cable jacket and is available to fit cables No. 1, 1/0, 2/0 and 3/0.

For details, circle No. 103 on Reader Information Card.

Arc-welding Machines

The availability of a new and complete line of M&T arc-welding machines was announced recently by Metal & Thermit Corp.

The new machines will be produced to M&T specifications by three different suppliers. Mid-States Welder Manufacturing Co., Chicago, will manufacture manual a-c transformer machines, d-c rectifier machines, a-c, d-c machines, inert arc-welding machines, and auxiliary equipment in ratings from 130 to 500 amp.

Rotary motor-generator welding machines will be made for M&T by Harnischfeger Corp., Milwaukee. CAPS (controlled-arc power supply) automatic and semiautomatic d-c machines will continue to be manufactured for the company by Glenn Pacific Power Supply Corp., which formerly was M&T Welding Products, Inc.

For details, circle No. 101 on Reader Information Card.

Tubular Welding Wires for Resurfacing Applications

A complete new line of tubular wires for semiautomatic resurfacing with semiautomatic welding units is announced by Hobart Brothers Co., Troy, Ohio.

These tubular wires are for application through conventional semiautomatic welders which automatically feed the wire when the arc is struck. They can be applied with either the open-arc or submerged-arc process.

The wires are of 7/64 in. diam and are furnished in coils of 12 in. ID x 3 in. wide, weighing approximately 50 lb.

For details, circle No. 102 on Reader Information Card.

Aluminum-alloy Sheet

Aluminum Company of America, Pittsburgh 19, Pa. is now producing sheet from alloy 5456—highest strength composition available in the readily weldable aluminum-magesium alloy series.

First introduced in plate gages only (0.250-in. minimum thickness), 5456 now is rolled in thicknesses ranging from 0.051 to 2.00 in. Mechanical properties, tempers and fabricating practices for the new, high-strength sheet have been established by Alcoa after extensive development work.

For details, circle No. 104 on Reader Information Card.

Vycor Nozzles

Tec Torch Co., Inc. of Carlstadt, N. J., manufacturers of Visuweld tungsten inert-gas welding equipment, announces the availability of a new and improved Vycor glass gas nozzle.

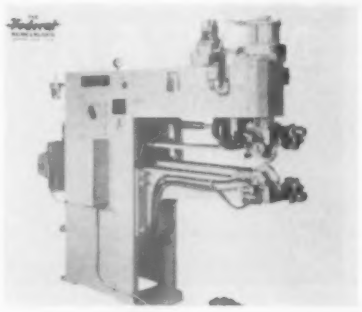
The company states that the Vycor nozzles remain clear and transparent throughout welding applications and have been found to withstand temperatures up to 3200° F.

For details, circle No. 105 on Reader Information Card.

Seam-welding Machines

An all new trim-line of standard seam-welding machines is being introduced by the Federal Machine and Welder Co. Warren, Ohio. These machines are available in three sizes ranging from 50 to 400 kva inclusive. Each size is available as a circular, longitudinal or universal machine in a range of standard throat depths and transformer sizes.

Some of the features are: One piece trim-line frame, anti-friction slide and new lower arm and transformer design. Machines are styled and constructed to deliver high-production runs at lower costs and



PLAST-IRON
GRADE B-171
POWDER
FOR
MILD STEEL, LOW HYDROGEN AND HARD-FACING
ELECTRODES

• IMPROVED QUALITY
• HIGHER DEPOSITION RATE
• FASTER OPERATION

Send for Technical Data and Working Sample

PM
PLASTIC METALS

PLASTIC METALS
Division
National-U.S. Radiator Corporation

5059 Bridge Street
JOHNSTOWN, PA.

For details, circle No. 26 on Reader Information Card

conform with modern production line requirements, according to the manufacturer.

For details, circle No. 106 on Reader Information Card.

Metal-spray Powder

A new metal-spray powder is now available from Wall Colmonoy Corp., 19345 John R. St., Detroit 3, Mich. Designated Colmonoy C-290, this material is high in chromium and nickel and contains wear-resistant chromium borides.

The manufacturer states that it has a low coefficient of friction and excellent oil retention qualities because of its fine porous structure.

The new material is specifically designed for reclamation of worn engine and compressor crankshafts, reclamation of the undersized manufacturers' rejects and modification of crankshafts in special high performance engines.

For details, circle No. 107 on Reader Information Card.

Welding Exhaust System

A new portable exhaust system said to be as convenient to use as a vacuum cleaner has been announced by Car-Mon Products Inc. 1541 West Devon Ave., Chicago, Ill. This new unit is primarily designed to remove fumes from welding, soldering, etc.

The unit is mounted on a rubber wheeled truck, rolls about easily to the source of work. It contains all the features of Car-Mon's stationary fume removal shop exhaust system. Receptor exhaust inlet with magnet-base fastens to the piece being worked on, or on any convenient metal nearby. The fan system draws up all poisonous gases, fumes, smoke and heat; directs them away from the worker.

For details, circle No. 108 on Reader Information Card.

Aluminum Welding

A new addition to the line of aluminum filler wire for the gas-shielded metal-arc and tungsten-arc inert-gas welding processes has just been announced by Airco, 150 E. 42nd St. New York 17, N. Y. Designated type A5556, this aluminum welding wire was developed to weld high-tensile aluminum alloys such as 5083, 5086 and 5456 that are being used in the construction of missile structures, ship superstructures, truck frames, storage tanks, gun-mount bases and diesel-engine bases.

The wire can be employed in all types of structural aluminum fabrication where postheat treatment is not feasible as a method of producing high-strength welded joints.

This magnesium-aluminum wire is available in Type "A" finish. It has been cleaned and specially treated to produce a consistently uniform surface.

For details, circle No. 109 on Reader Information Card.

Pipe-welding Machine

The development of an automatic circumferential welding machine for butt welding aluminum pipe has been announced by Aluminium Ltd. Sales, Inc., 630 Fifth Ave., New York, N. Y., a major Canadian aluminum producer.

The lightweight (35-lb) welding machine is held in position by a strap clamp, and the welding gun and cable drum gear travel around the axis of the pipe. A $4^1/_2$-in. diam standard pipe can be butt welded in less than one minute, without any weld programming.

Arc-travel speed is variable from 50 to 250 ipm and the direction of rotation can be instantly reversed.

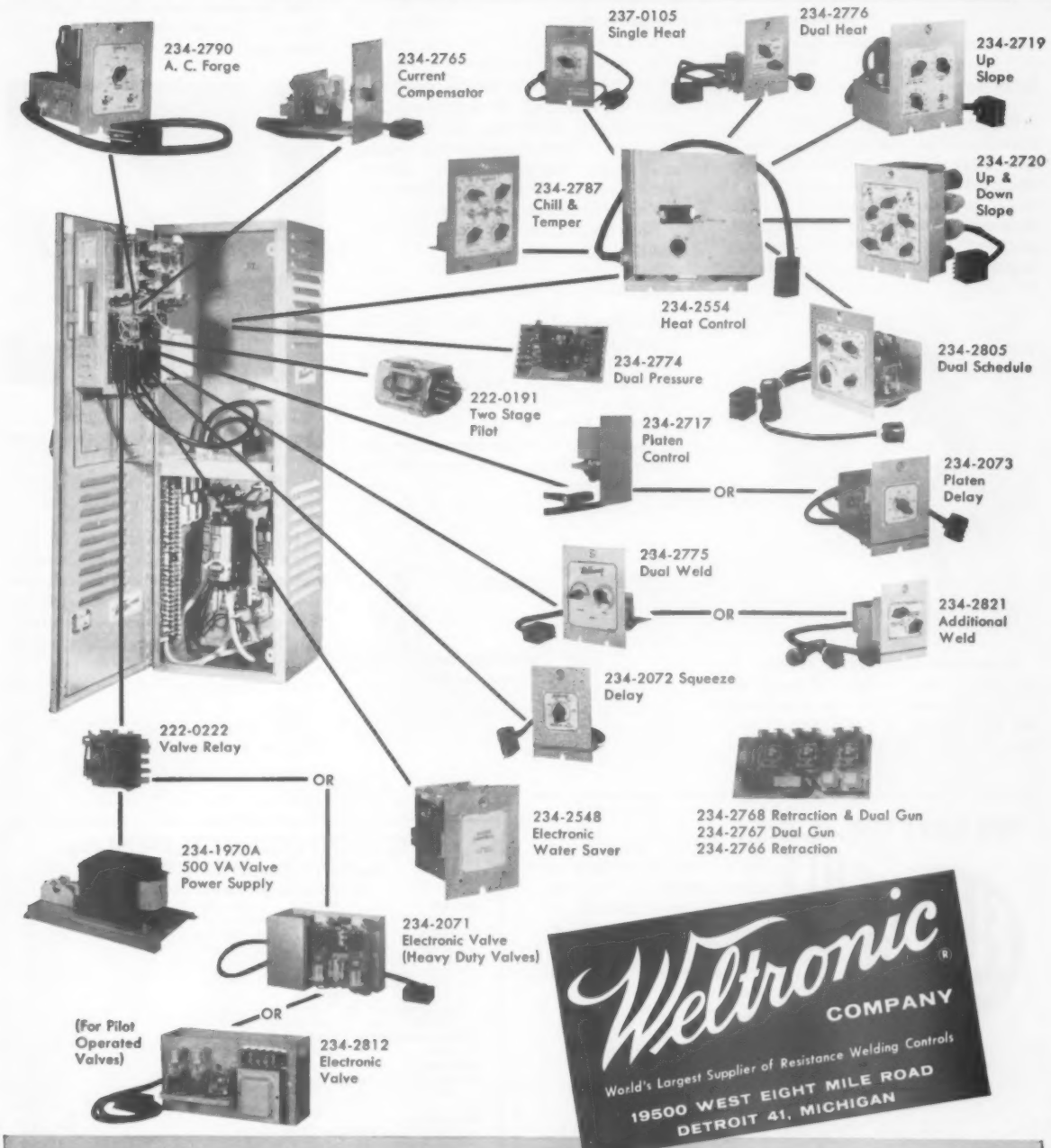
The welding unit is air cooled to handle 200 amp continuously and will join pipe from 2 to 8 in. in diam.

For details, circle No. 110 on Reader Information Card.

Now!!

You Can Handle any WELDING JOB with this "Standard" Welder Control

A COMPLETE "PACKAGE"... These new controls are available as complete "package" units—completely wired and ready to install. And every control is equipped with a Weltronic, tube firing, 3B Timer.



Weltronic® COMPANY

World's Largest Supplier of Resistance Welding Controls

19500 WEST EIGHT MILE ROAD

DETROIT 41, MICHIGAN

For details, circle No. 27 on Reader Information Card

ACRO WELDER MFG. CO.
MILWAUKEE
WELDING ENGINEERS
MACHINERY BUILDERS
ESTABLISHED 1936

For details, circle No. 28 on Reader Information Card

Ammeter

Columbia Electric Mfg. Co., Cleveland 14, Ohio, announces a new Type PB Tong Test Ammeter, designed for measuring small amounts of direct current, in 1/2 amp divisions, from 0 to 10 amp. In addition, the Type PB can be used to read both ac and dc up to 20 amp.

Measurements are taken by clamping the tongs around the electrical conductor, without breaking the circuit or insulation. Jaws can accommodate conductors up to 1/2 in. diam. Two ranges are provided on one dial, 10–0–10 amp for dc only and 0–20 amp for both ac and dc. The 10–0–10 dc scale utilizes an "electrical zero" which is established by use of a magnetic source attached to the instrument.

For details, circle No. 111 on Reader Information Card.

Aluminum "C" Clamps

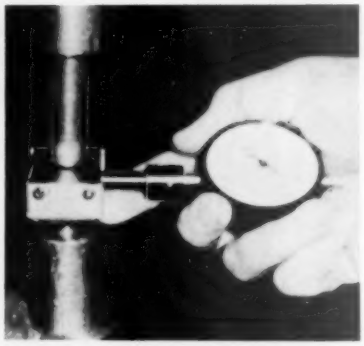
Automatic Tool Products Co., 676 Pennsylvania Ave., Elizabeth, N. J. has announced a new series of aluminum alloy automatic "C" clamps with fast action push-button control. Pressing the top button on these new clamps disengages the screw, permitting it to travel freely forward and backward. Clamp cannot be opened until tension on screw is released by a turn of the handle. Buttress threading assures positive locking control.

Plated screws are available for use in welding shops.

For details, circle No. 112 on Reader Information Card.

Electrode Pressure Gage

Availability of a new type gage to measure electrode pressure in resistance-welding equipment is announced by Instrument Control Co. 1554 Nicollet Ave., Minneapolis 3, Minn. The gage will measure up to 2500 psi.



The gage functions by measuring the deflection of two simple beams as pressure is applied to them. Accuracy is said to be ±4%, and the gages are calibrated against precision standards.

Intended for general shop use, the gage has no intricate linkages to get out of order, and the dial indicator is quickly and easily zero-adjusted. The gage is 5/8 in. thick between load application points, making it suited to such measuring jobs as checking electrode pressure on welding equipment.

For details, circle No. 113 on Reader Information Card.

WE HAVE THE FLUX RIGHT For Your Job

62 years of experience in scientific development in welding

Whatever the particular job you have to do—we have the right FLUXINE you need. Besides our 25 FLUXINES we carry a complete line of "KOP-R-ARC" coated rods for welding copper and all copper alloys.

Write on company letterhead for chart and generous sample stating which FLUXINE desired.

KREMBS & COMPANY
(Est. 1875)
Dept. W, 669 W. Ohio St., Chicago 10, Ill.

For details, circle No. 29 on Reader Information Card

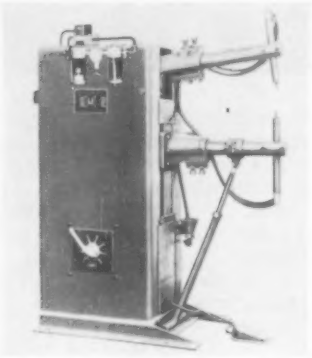
WELDING JOURNAL
General Advertising Rates
Effective January 1, 1960

RATES:	1 time	3 times	6 times	12 times*
1 page	$450.00	$410.00	$390.00	$350.00
2/3 page	320.00	295.00	270.00	260.00
1/2 page	250.00	230.00	210.00	190.00
1/3 page	185.00	165.00	160.00	150.00
1/4 page	145.00	140.00	135.00	130.00
1/6 page	110.00	100.00	95.00	80.00
1/8 page	90.00	80.00	75.00	70.00
*24 times rate, for full page only: $330				
*36 times rate, for full page only: $300				
PREFERRED POSITIONS:				
1 page	490.00	450.00	435.00	395.00
COVERS				
Inside front cover	.....	.....	$485.00	$440.00
Inside back cover	.....	.....	440.00	400.00
Outside back cover	.....	.....	.....	480.00
COLORS:				
Inside pages, standard AAAA color, extra				85.00
Inside pages, special color, extra				100.00
Color on cover, extra				75.00

Resistance-welding Machines

The Universal Electroweld Division, Electric Arc, Inc., 152–1 Jelliff Ave., Newark 8, N. J., has announced the development of improved types of rocker arm spot-welding machines embodying features that are said to add to their ease of operation and maintenance and broaden their work range. The new welding machines are part of a recently announced line of single-phase resistance welding machines developed by the Universal Electroweld Division to bring greater precision, economy and flexibility to single-phase welding.

Made in both air-actuated and foot-operated models, the new Electroweld Rocker Arm machines have kva ratings of from 10 to 75, and throat depths ranging from 12 to 36 in. According to the Electroweld Division, the construction and design of the machines insure high-production performance without need for major repairs or parts replacement.



For details, circle No. 114 on Reader Information Card.

Surface Protection

"Protex" is a special surface protection compound for use with the air-carbon-arc process. The manufacturer Arcair Co., Lancaster, Ohio, claims that the new compound will not blow away from the surface being worked and that lack of this characteristic prevents other compounds from being used during these operations.

Protex is applied to the surface with an ordinary paint brush and there is no waiting period for it to dry before beginning work. Though not required on most metals during air-carbon-arc operations, it is especially valuable for use on stainless steels, machined surfaces and similar applications. It can also be used to advantage for welding operations, and to prevent the formation of scale during heat treat or stress-relieving operations. After use, it is easily wiped off with a dry cloth.

For details, circle No. 115 on Reader Information Card.

Safety Glasses

Bausch & Lomb Optical Co. Rochester 2, N. Y. announces the addition of the new M-70 metal frame safety glass to its line of protective eyewear. The M-70 combines a durable metal frame with Bal-Safe lenses for greater protection and smart appearance. The new model features a re-

HI-AMP

ELECTRODE HOLDERS

CABLE ATTACHMENTS

GROUND CLAMPS

Offers

T.P.C.*

* THREADED POWER CONNECTION

Excessive heat in a welding circuit is oftentimes caused by a resistance build-up at some point in the welding circuit due to connections being loose or oxidization setting up in a mechanical type of terminal connection.

Shown in the above "cut-a-way" picture of an Electrode Holder is the new HI-AMP, T.P.C. type of connection that can be adapted to ground clamps and quick disconnect plugs as well as to electrode holders.

T.P.C. means a Threaded Power Connection using the pressure of threads on a sleeve to drive the ends of any welding cable down into the depth of a cable socket, then locked into place with threaded plugs. An excellent electrical connection as well as providing direct contact with the welding cable to the accessory so that maximum heat is conducted into the heat-absorbing cable.

ASK YOUR WELDING SUPPLY HOUSE FOR FURTHER INFORMATION

354 W. ADAMS ST. LENCO, INC. JACKSON, MO.

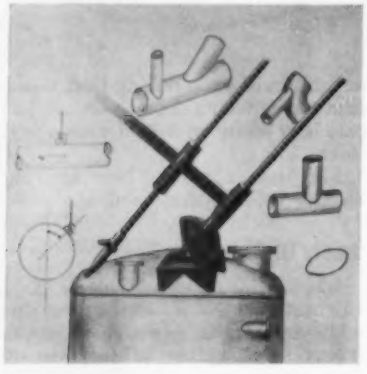
For details, circle No. 30 on Reader Information Card

designed, expansion-type endpiece which allows easy assembly of both lenses and side shields.

For details, circle No. 116 on Reader Information Card.

Pipe-marking Tool

A pipe-marking tool which is said to eliminate the need for patterns and templates is announced by Sury Engineering and Sales Co., Box 103, Glen Dale, W. Va.

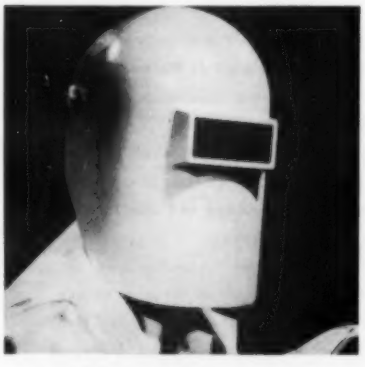


The new tool can be used to lay out circles, ellipses and various other intersections of contoured surfaces.

For details, circle No. 117 on Reader Information Card.

Welding Helmets

A new, standard size fiberglass-reinforced plastic welding helmet Model 1210, which has a straight front to provide maximum ventilation and more chest protection, has been added to the line of colored welding helmets manufactured by Hobart Brothers Co., Troy, Ohio.

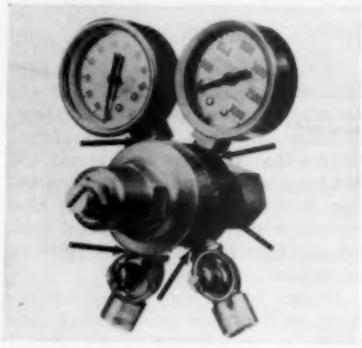


The helmet differs from conventional welding helmets in that the front is molded straight instead of curved to fit underneath the operator's face, permitting greater circulation of air and providing more chest protection.

For details, circle No. 118 on Reader Information Card.

Regulator Sealant

C. A. Norgren Co., Englewood, Calif., is using Loctite, a liquid polymer sealant, in their line of CO_2 pressure regulators. Joints sealed with this material can be broken for service without difficulty. In addition, the absence of solid particles in the sealant is said to be an advantage, since no clogging in



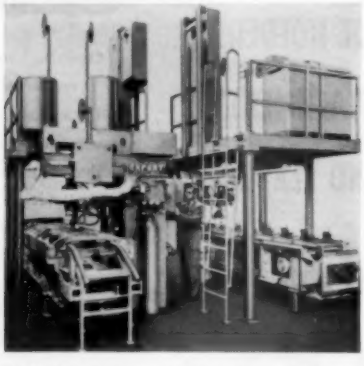
valve operation will occur. The liquid polymer material is a product of American Sealants Co., 265 Woodbine St., Hartford 6, Conn.

Loctite reportedly withstands heat to 300° F and has been a successful sealant against CO_2, oxygen, freon, nitrogen, acetylene and liquid petroleum gases.

For details, circle No. 126 on Reader Information Card.

Automated Welding Machine

A new over-and-under transfer system said to improve the efficiency of automatic transfer machines and automated welding machines is now available from Expert Automation



Machine Co., 17144 Mt. Elliott Ave., Detroit 12, Mich. According to the manufacturer, this over-and-under design, when compared to a rotary-dial type machine, reduces floor-space requirements, increases production and facilitates material-handling operations.

For details, circle No. 119 on Reader Information Card.

Joint Preparation

A specially designed fixture mounted on a standard Wallace Cut-off Unit is part of a new system for preparing pipe or tube ends for welded structures. Called the "Dewitt System for Joint Preparation," the method was developed by the

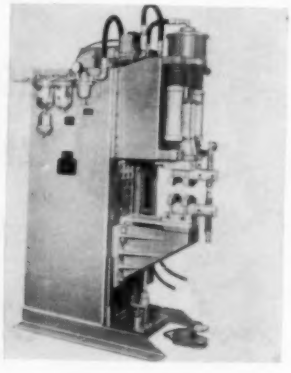
Wallace Supplies Mfg. Co., 1300 Diversey Parkway, Chicago 14, Ill. The method is said to do away with templates and marking, and to result in considerable savings over conventional methods of joint preparation.

For details, circle No. 120 on Reader Information Card.

Projection-welding Machine

A new single-phase projection welding machine has been developed by the Universal Electroweld Division, Electric Arc, Inc., 152-1 Jelliff Ave., Newark 8, N. J.

Single-phase welding machines are the least expensive type of resistance-



welding machines, and, according to the company, the development of the new machine permits users to produce work to stringent specifications with a minimum investment.

The new welding machine features a special "Heat-Vector" device for the automatic control of the up and down slope of the welding current.

For details, circle No. 121 on Reader Information Card.

Bronze Welding Rods

Air Reduction Sales Co., 150 E. 42nd St., New York 17, N. Y., has announced the addition of three new extruded thin flux-coated bronze rods to its line of gas-welding supplies. Designated Airco No. 20 (bronze), Airco No. 22 (manganese bronze) and Airco No. 27 (low-fuming bronze), these high-speed production rods are designed for work where only a small amount of flux is needed to prepare and clean the weld, and where the time for the removal of flux residue is at a premium.

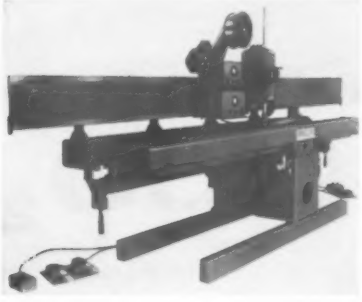
These rods can be used to weld, braze and braze weld steel, copper, cast iron, brass or bronze in the manufacture of furniture, steel cabinets, truck and auto bodies, railroad cars, vaults and many other consumer products made of tubular and sheet metals.

Airco's extruded thin flux-coated rods are available in $^3/_{32}$, $^1/_8$, $^5/_{16}$ and $^1/_4$ in. diam.

For details, circle No. 122 on Reader Information Card.

Weld-seaming Fixture

A twin-mandrel weld-seaming fixture has been designed by Pandjiris Weldment Co., 5151 Northrup Ave., St. Louis 10, Mo. The new fixture consists of opposed double-mandreled seamers with both holding and clamping mandrels utilizing the same welding head. While the

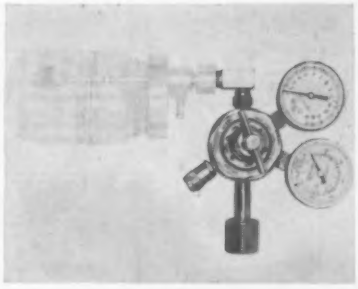


welding cycle takes place on one side of the fixture, the next piece to be welded is being loaded in the opposite side. Reported advantages are continuous arc time and operational utility of one automatic welding head and power source.

For details, circle No. 123 on Reader Information Card.

Oxygen-therapy Regulator

Introduction of a new oxygen-therapy regulator, engineered for accurate delivery of oxygen within medically acceptable limits, has been



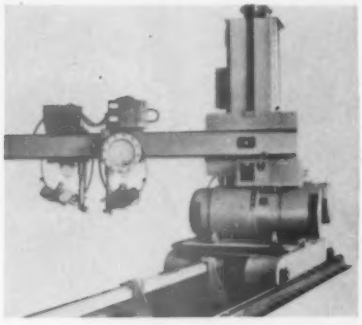
announced by Smith Welding Equipment Corp. 2855 Park Ave., Minneapolis, Minn.

Designed for use with any bubble-type humidifier, Smith's H730 regulator is for emergency administration of oxygen by such organizations as hospitals, industrial safety divisions and police and fire departments.

For details, circle No. 124 on Reader Information Card.

Welding-head Manipulator

A new mechanized welding head manipulator to facilitate the automatic welding of both large and small, simple and complex contoured products has been announced by the World Electric Co., 4616 Prospect Ave., Cleveland, Ohio.

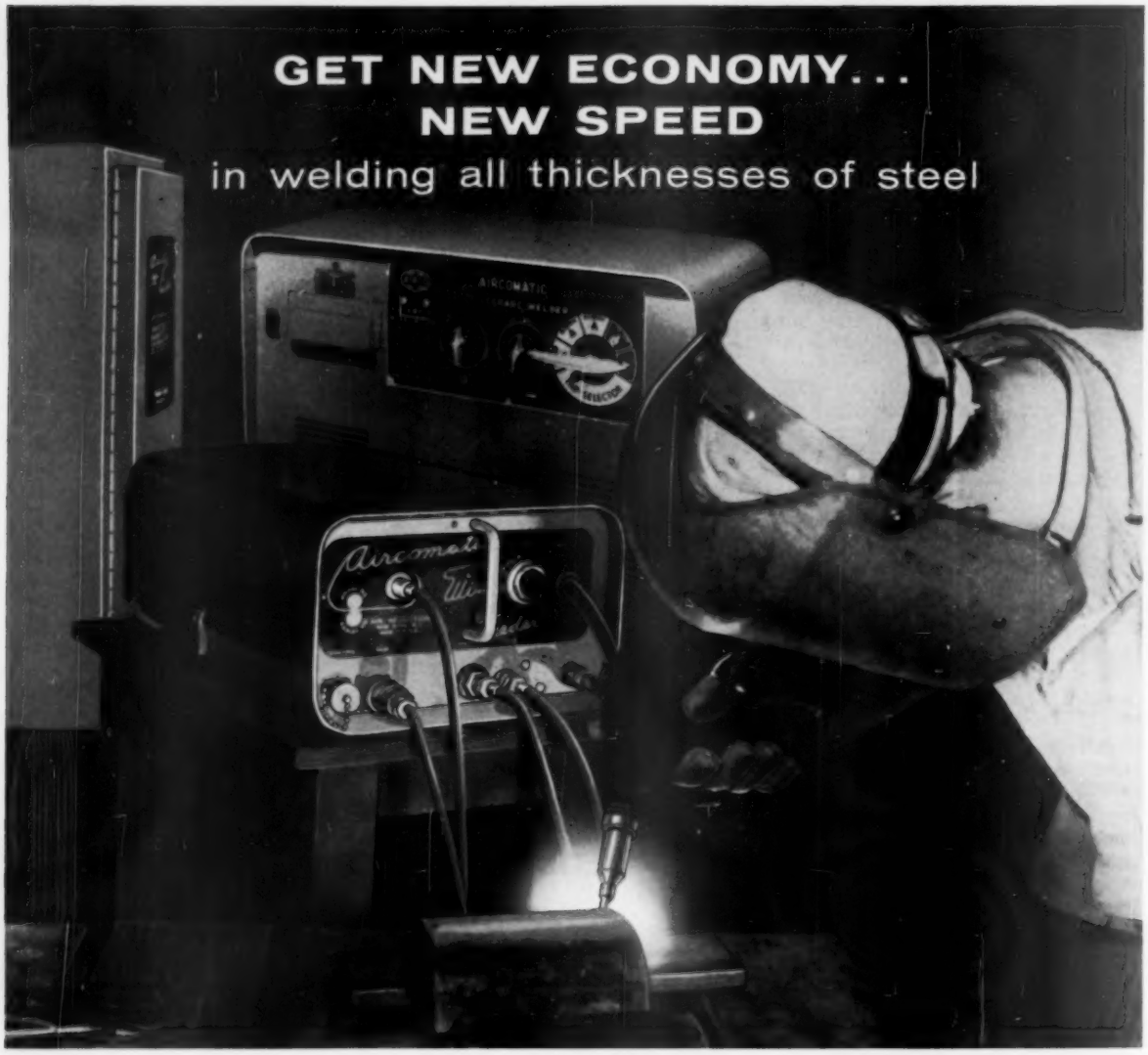


It is also suited for fillet welding of tapered building columns, cover plates, bridge girders and other structural fabrications.

Trade named the "Robot," this Welco manipulator features simultaneous boom, carriage column and base travel. It can be furnished with either single or dual heads for floating or fixed operations.

For details, circle No. 125 on Reader Information Card.

LOOKING FOR THE BEST? Buy
INDEPENDENT
Acetylene Cylinders
Unconditional Guarantee
Proven Filler - No "Spitting"
No voids - No soft Spots
Seamless Cylinders for Durability
Alloy steels for Lighter Weight
Cylinder Shells - Meet all ICC Requirements
All Cylinders "WHEELABRATOR" cleaned
Standard Sizes in Stock - Special Sizes on Request
Independent also manufactures Low Pressure Acetylene Generating Plant Equipment.
SEND YOUR INQUIRIES TODAY TO
INDEPENDENT ENGINEERING COMPANY, Inc.
Manufacturers of
CONSULTING IECO DESIGNING
RESEARCH
CYLINDERS AND GAS PRODUCING EQUIPMENT
ACETYLENE - OXYGEN - NITROGEN - ARGON
O'FALLON 2, ILLINOIS
For details circle, No. 31 on Reader Information Card



using PURECO CO_2

Here's a *new way* to weld mild steel, manually. Reduce costs and raise weld quality at the same time with *Dip Transfer* CO_2 Welding*. Gives you very low spatter; hydrogen-free welds; makes manual welds easy in any position. Use PURECO Welding Grade CO_2 *for gas shielding*, at the purity and price to keep welding quality up and cost down. The complete line of PURECO CO_2 supply systems includes: receivers, high pressure receiver tubes, converters, and cylinders.

Get full information about CO_2 in welding from PURECO Technical Sales Service. Call your PURECO representative today. There are more than 100 locations from coast to coast for your convenience.

*Patent No. 2886696

PURECO CO_2

Pure Carbonic Company

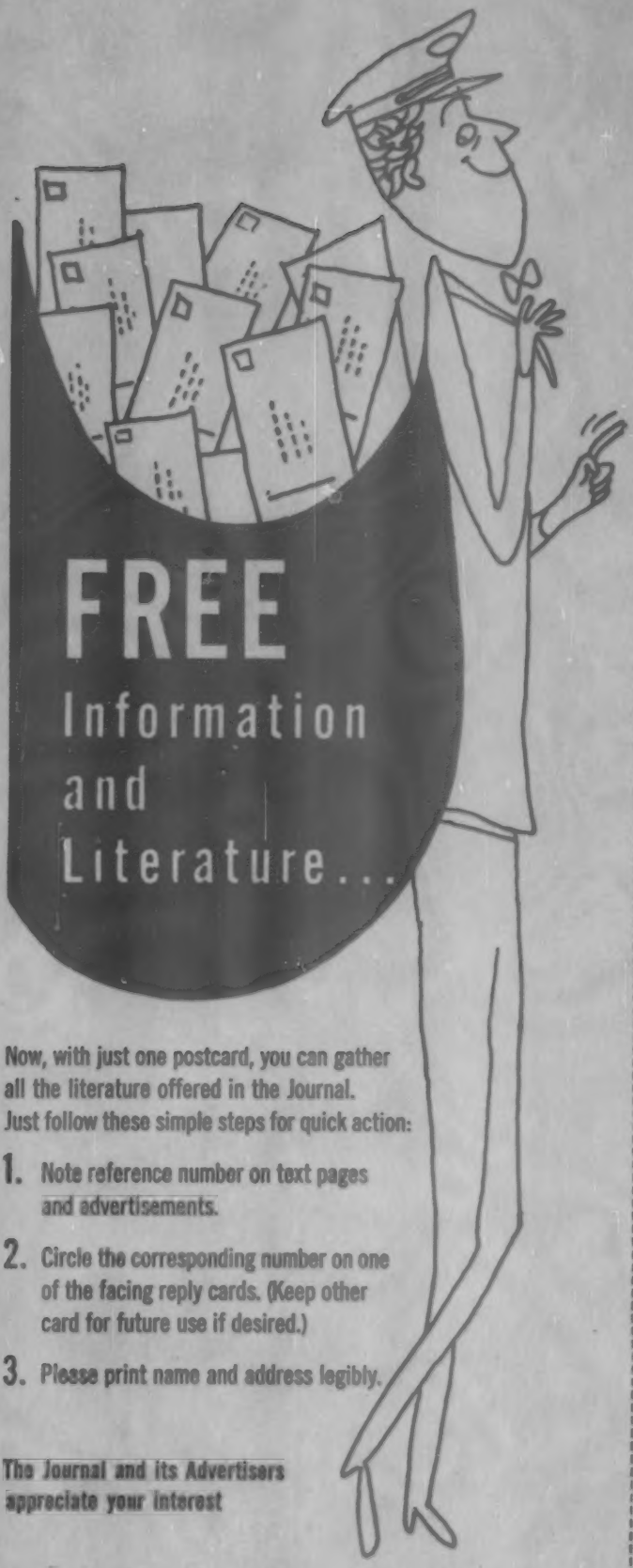
A Division of Air Reduction Company, Incorporated

GENERAL OFFICES 150 EAST 42nd STREET, NEW YORK 17, N. Y.

NATION-WIDE "DRY-ICE" SERVICE—DISTRIBUTING STATIONS IN PRINCIPAL CITIES

For details, circle No. 32 on Reader Information Card

READER INFORMATION CARD



FREE
Information and Literature...

Now, with just one postcard, you can gather all the literature offered in the Journal. Just follow these simple steps for quick action:

1. Note reference number on text pages and advertisements.
2. Circle the corresponding number on one of the facing reply cards. (Keep other card for future use if desired.)
3. Please print name and address legibly.

The Journal and its Advertisers appreciate your interest

October, 1959

Card valid until December 31, 1959

Please send me, without cost or obligation, further information and literature on items circled below:

1	26	51	76	101	126
2	27	52	77	102	127
3	28	53	78	103	128
4	29	54	79	104	129
5	30	55	80	105	130
6	31	56	81	106	131
7	32	57	82	107	132
8	33	58	83	108	133
9	34	59	84	109	134
10	35	60	85	110	135
11	36	61	86	111	136
12	37	62	87	112	137
13	38	63	88	113	138
14	39	64	89	114	139
15	40	65	90	115	140
16	41	66	91	116	141
17	42	67	92	117	142
18	43	68	93	118	143
19	44	69	94	119	144
20	45	70	95	120	145
21	46	71	96	121	146
22	47	72	97	122	147
23	48	73	98	123	148
24	49	74	99	124	149
25	50	75	100	125	150

Mail me a list of AWS Publications ☐

NAME _____

TITLE _____

COMPANY _____

PRODUCT _____

ADDRESS _____

CITY & ZONE _____ STATE _____

FIRST CLASS
PERMIT NO. 9288
NEW YORK, N. Y.

Business Reply Card
No postage necessary if mailed in the United States

4¢ POSTAGE WILL BE PAID BY

Welding Journal
33 West 39th Street
New York 18, N. Y.

FIRST CLASS
PERMIT NO. 9256
NEW YORK, N. Y.

Business Reply Card
No postage necessary if mailed in the United States

4¢ POSTAGE WILL BE PAID BY

Welding Journal
33 West 39th Street
New York 18, N. Y.

October, 1959

Card valid until December 31, 1959

Please send me, without cost or obligation, further information and literature on items circled below:

1	26	51	76	101	126
2	27	52	77	102	127
3	28	53	78	103	128
4	29	54	79	104	129
5	30	55	80	105	130
6	31	56	81	106	131
7	32	57	82	107	132
8	33	58	83	108	133
9	34	59	84	109	134
10	35	60	85	110	135
11	36	61	86	111	136
12	37	62	87	112	137
13	38	63	88	113	138
14	39	64	89	114	139
15	40	65	90	115	140
16	41	66	91	116	141
17	42	67	92	117	142
18	43	68	93	118	143
19	44	69	94	119	144
20	45	70	95	120	145
21	46	71	96	121	146
22	47	72	97	122	147
23	48	73	98	123	148
24	49	74	99	124	149
25	50	75	100	125	150

Mail me a list of AWS Publications ☐

NAME _____

TITLE _____

COMPANY _____

PRODUCT _____

ADDRESS _____

CITY & ZONE _____ STATE _____

Index to ADVERTISERS

1040	Acro Welder Mfg. Co.
Outside Back Cover	Air Reduction Sales Co.
955	Alloy Rods Company
1032	All-State Welding Alloys Co., Inc.
1024, 1025	Aluminum Company of America
Inside Back Cover	The American Brass Co.
1034, 1035	Arcos Corporation
1007	Berkeley-Davis Incorporated
1025	S. Blickman, Inc.
1033	Brown Boveri Co.
1005	The Budd Company
1023	Cayuga Machine and Fabricating Co. Inc.
1004	Chicago Hardware Foundry Co.
1026, 1027	Eutectic Welding Alloys Corporation
995	Harnischfeger Corp.
949	Hobart Brothers Co.
1043	Independent Engineering Company, Inc.
1040	Krembs & Company
1041	Lenco, Inc.
953	Linde Company, Division of Union Carbide Corporation
1000, 1001	Messer Cutting Machines, Inc.
1008, 1009	Metal & Thermit Corporation
1029	Micro Switch
958	Miller Electric Manufacturing Co.
1022	National Carbide Company
1038	National-U.S. Radiator Corporation
951	National Welding Equipment Co.
956	New England Welding Conference
1044	Pure Carbonic Company
1003	Square D Company
1036	Stulz-Sickles Company
1031	Tempil® Corporation
953	Union Carbide Corporation Linde Company
1011, 1012	United Engineering Center
999	Vickers Inc., Electric Products Div.
Inside Front Cover	Victor Equipment Co.
1017	Wall Colmonoy Corp.
1029	Weldmatic, Div. of Unitek Corp.
1039	Weltronic Inc.
1014, 1015	Westinghouse Electric Corp.

Welding Research

Sponsored by the Welding Research Council of the Engineering Foundation

WRC

SUPPLEMENT TO THE WELDING JOURNAL, OCTOBER 1959

Welding of Nickel-Molybdenum Alloys

Alloys investigated found to be readily weldable by the inert-gas-shielded tungsten-arc process and to exhibit no difficulties with regard to cracking and porosity

BY G. M. SLAUGHTER, P. PATRIARCA AND R. E. CLAUSING

Introduction

The relatively extreme conditions of corrosion encountered in the petroleum, petro-chemical and chemical industries have necessitated the use of structural materials possessing outstanding resistance to corrosion. In order to handle the various corrosive liquids, the structural materials must be capable of being readily fabricated into pressure vessels, heat exchangers, tanks and other related equipment. Nickel-base alloys containing molybdenum have been utilized extensively in a large number of these applications, including service in hydrochloric acid, sulfuric acid, oxidizing salts, alkaline solutions and many other highly corrosive media.[1-4]

The American Society of Mechanical Engineers' Pressure Vessel Code has recognized the nickel-molybdenum alloys Hastelloy Alloy B and Hastelloy Alloy C as being suitable materials for use in unfired pressure vessels.[5, 6] The service temperature limitations are 650 and 1000° F, respectively. In addition, these alloys have been used extensively at higher temperatures for such applications as turbine blades, conveyor chains and bolting and shafting components.[7] Other nickel-molybdenum alloys also have been utilized frequently for various industrial applications, but these have not yet been Code approved.

Nuclear-reactor systems utilizing molten fluoride salts as the fluid fuels are very attractive as heat sources for modern steam-power plants.[8, 9] One important requirement of these reactor systems is that the structural materials possess exceptionally good corrosion resistance in the operating temperature range of 1200–1300° F. The nickel-molybdenum alloys adequately meet this requirement, and, in addition, their elevated-temperature strengths are comparable to those of the conventional high-temperature alloys. The 1500° F stress-rupture properties of a commercially available nickel-molybdenum alloy (Hastelloy Alloy B) are shown in Fig. 1 and are compared with those of Type 316 stainless steel and Inconel.

This commercially available alloy (Ni – 27% Mo – 5% Fe) was

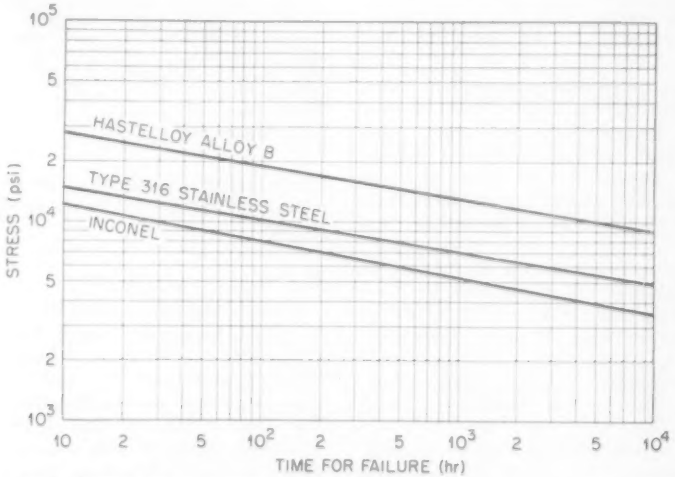


Fig. 1—Stress-rupture properties of Hastelloy Alloy B, Type 316 stainless steel, and Inconel at 1500° F

G. M. SLAUGHTER, P. PATRIARCA and R. E. CLAUSING are associated with the Metallurgy Division, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Paper presented at the AWS 40th Annual Meeting held in Chicago, Ill., Apr. 6–10, 1959.

Table 1—Chemical Composition of Wrought Plate and Weld Filler Wire

Material	Chemical composition, wt-%										
	Ni	Mo	Fe	Cr	Mn	Si	C	P	S	V	Co
Hastelloy-Alloy-B plate	Bal.	26.55	5.05	0.62	0.68	0.61	0.03	0.006	0.013	0.37	0.94
Hastelloy-Alloy-B filler wire	Bal.	27.10	5.05	0.38	0.85	0.35	0.02	0.001	0.012	0.28	0.35
Hastelloy-Alloy-W filler wire	Bal.	24.36	5.20	5.94	0.40	0.29	0.05	0.004	0.012	0.28	0.74
INOR-8 plate and filler wire	Bal.	16.65	4.83	7.43	0.48	0.04	0.06	0.010	0.015	0.10	0.51

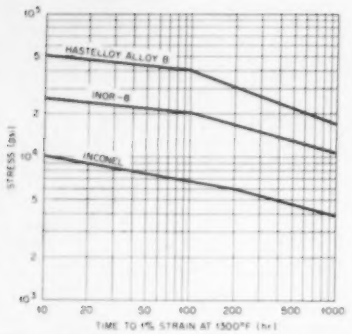


Fig. 2—Comparison of creep properties of Hastelloy Alloy B, INOR-8 and Inconel in molten salts at 1300° F

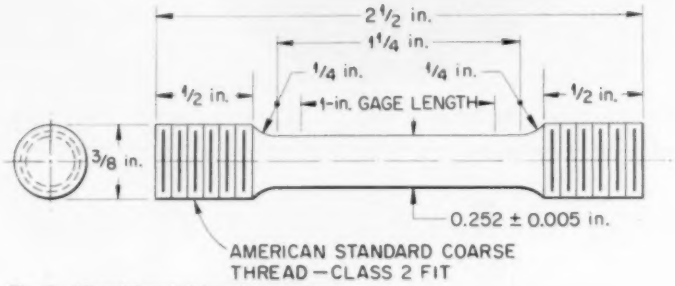


Fig. 3—All-weld-metal tensile specimen

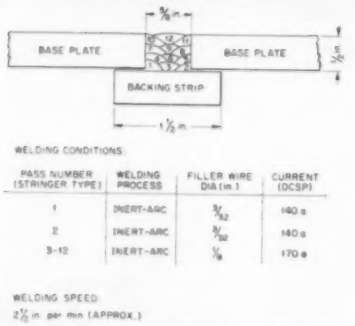


Fig. 4—Welding sequence for test plates

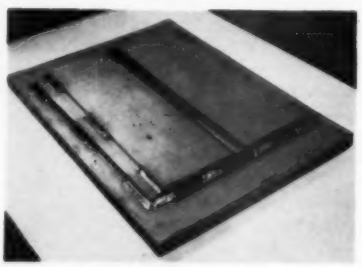


Fig. 5—Setup for weld-test plate fabrication

investigated in detail by the Metallurgy Division of the Oak Ridge National Laboratory in order to determine its general suitability for service in the 1200–1300° F temperature range.[10, 11] Unfortunately, age hardening of this alloy in this temperature range makes it subject to significant embrittlement, both at room and at elevated temperatures. In addition, the oxidation resistance is marginal and becomes poor at temperatures above 1500° F.

Consequently, an extensive program was carried out by the Metallurgy Division to develop a non-age-hardenable high-strength nickel-molybdenum alloy which possesses excellent corrosion resistance to the molten salts and good oxidation resistance. An alloy, INOR-8 (Ni – 17% Mo – 7% Cr – 4% Fe), which adequately satisfied these conditions[5, 9] was developed and is now commercially available. The favorable creep properties of INOR-8 as compared with those of Hastelloy Alloy B and Inconel in molten salts at 1300° F are shown in Fig. 2.

Recognizing that a study of the weldability of these alloys was needed, the properties of welds in Hastelloy Alloy B and INOR-8 at the temperatures of interest were determined. A commercially available filler metal Hastelloy Alloy W[12] (Ni – 25% Mo – 5% Cr – 5% Fe), which age hardens to a lesser extent than Hastelloy Alloy B, was also investigated, since it was used extensively for test-component fabrication during the time interval in which INOR-8 was under development.

Material

The Hastelloy-Alloy-B and INOR-8 base plate used for this study was 1/2 in. thick. Hastelloy-Alloy-B weld wire, 3/32 and 1/8 in. diam, was used for the deposition of the test welds of this material. Hastelloy-Alloy-W weld deposits on Hastelloy-Alloy-B plate were also made with filler wire of these two sizes.

At the time of this investigation, INOR-8 filler wire was not available for the deposition of welds on this material. Consequently, strips of approximately square cross section were sheared from 0.10-in.-thick sheet material.

The chemical analyses of these materials are shown in Table 1.

Equipment

The inert-gas-shielded tungsten-arc process was used throughout the investigation for the preparation of all weldments. The 0.252-in.-diam reduced-section all-weld-metal tensile specimens shown in Fig. 3 were machined in accordance with the recommendations of the American Welding Society.[13] Testing was performed on a 12,000-lb-maximum hydraulic tensile-testing machine at a strain rate of 0.05 ipm.

Aging of hardness, tensile and metallographic specimens at elevated temperatures was performed in evacuated quartz capsules to eliminate the effect of the atmosphere. The encapsulated specimens were heated in box-type electric-resistance furnaces.

The etchant used in the metallographic examination was chrome regia (1 part 1% chromic-acid solution, 3 parts hydrochloric acid and 10 parts water). Etching was performed at room temperature for times varying from 3 to 5 sec.

Hardness measurements were made with a Vickers diamond pyramid indenter with a 10-kg load.

Experimental Procedure

The preparation of the numerous all-weld-metal tensile, hardness and

metallographic specimens used in this investigation required the manual deposition of extensive quantities of weld metal in the grooves of weld test plates. A joint design was selected which would provide a relatively large weld-metal cross section. Base-metal plates, $^1/_2$ in. thick and 20 in. long, were machined and assembled to permit a square-groove weld with a $^5/_8$ in. width. All-weld-metal 0.252-in.-diam reduced-section tensile specimens were machined from these weld test plates, and hardness and metallographic specimens of adequate size were readily obtained from the remaining portions of the plate.

A sketch showing the welding sequence used in the fabrication of a typical weld test plate is shown in Fig. 4. A photograph of a typical setup after completion of welding is shown in Fig. 5. The utilization of the large hold-down plates provided restraint and prevented appreciable distortion of the base plate during welding. The welding operators were qualified in accordance with approved practices for high-quality applications.[14] The data for each weld were recorded, evaluated for possible trends or discrepancies and filed for reference.

The welded joints were then dye-penetrant inspected and radiographed to determine the presence of porosity, cracking or other defects. All the alloys discussed in this report were found to be readily weldable, and no difficulties were encountered. The all-weld-metal tensile, hardness and metallographic specimens were machined from the 20-in.-long weld deposits.

All-weld-metal tensile specimens were tested at room temperature and at 1200° F in the as-welded and welded-and-aged conditions. Hardness traverses across welded joints were made in order to determine the extent of age hardening occurring in both weld metal and base plate at various temperatures and time intervals.

Results

Since the aging behavior of Hastelloy-Alloy-B and Hastelloy-Alloy-W welds appeared to be the result of the precipitation of a phase or phases, the effects of aging time and aging temperature on the room-temperature hardness were studied and correlated with the observed microstructures. The mechanical properties of weld metal, before and after aging at 1200° F, were also determined. Welds of the nonage-hardenable alloy, INOR-8, were included in this study for comparative purposes.

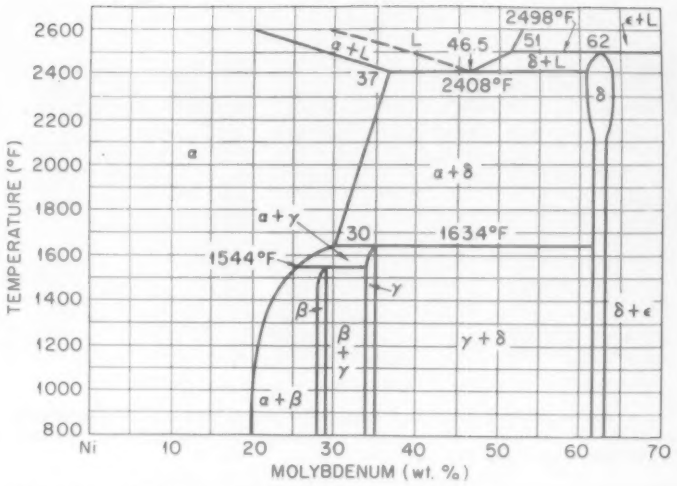


Fig. 6—Nickel-molybdenum equilibrium phase diagram

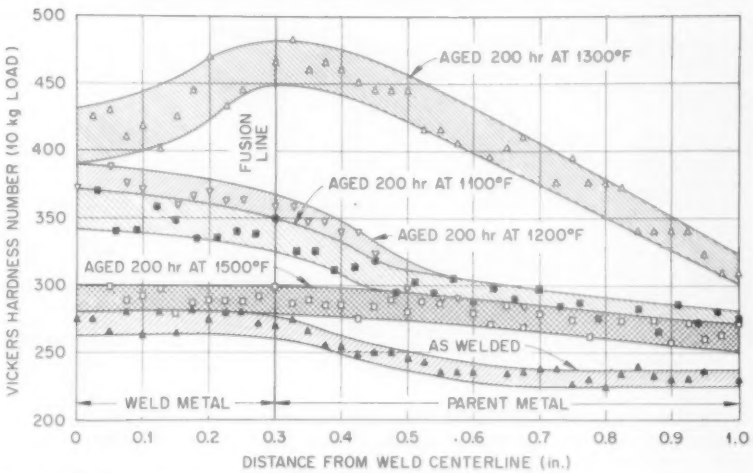


Fig. 7—Effect of aging temperature on room-temperature hardness of Hastelloy-Alloy-B welds

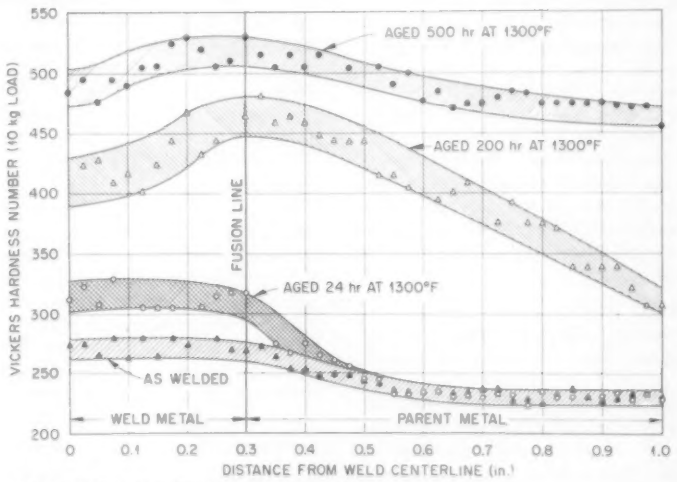


Fig. 8—Effect of aging time on room-temperature hardness of Hastelloy-Alloy-B welds

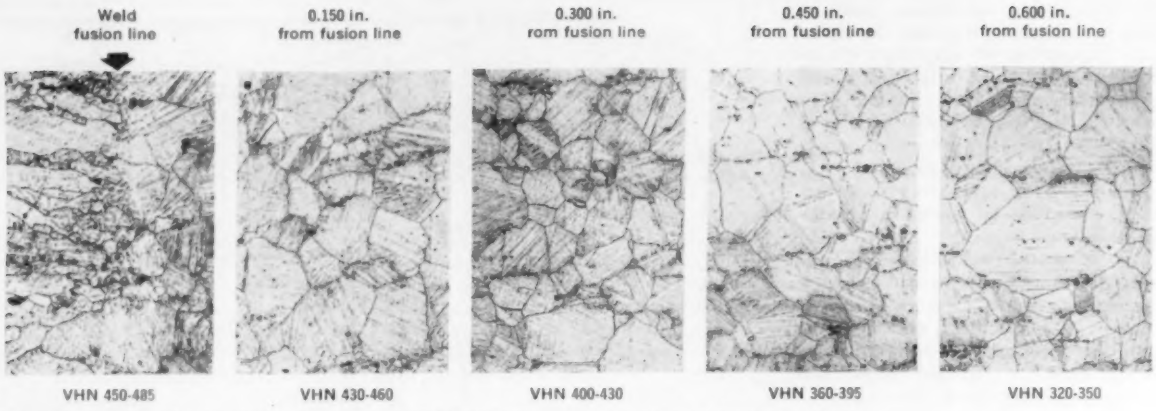


Fig. 9—Composite showing increasing amount of precipitate in Hastelloy-Alloy-B base plate as weld fusion-line is approached. Aging treatment, 200 hr at 1300° F. Etch, Cr. Regia. X 200 (Reduced by 1/3 upon reproduction)

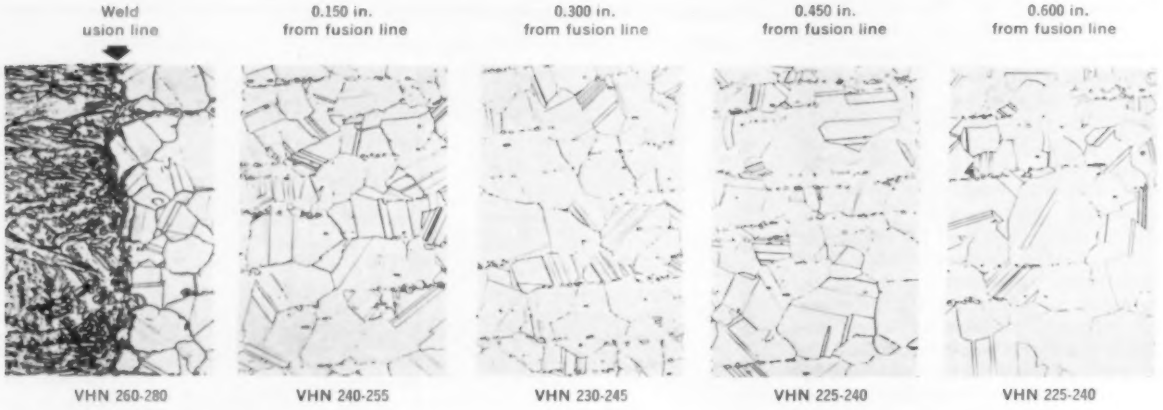


Fig. 10—Composite showing microstructure of Hastelloy-Alloy-B weldment in as-welded condition. No obvious precipitate can be seen. Etch, Cr. Regia. X 200. (Reduced by 1/3 upon reproduction)

The nickel-molybdenum binary-phase diagram shown in Fig. 6[15] was used extensively as a guide in this investigation, as was other available information on this system.[16,17] This information was particularly useful in interpreting the mechanical property, hardness and microstructural changes occurring as a result of aging, although the presence of chromium and other elements have been shown to have some influence upon the phase boundaries.[18]

Hardness Studies

Hastelloy Alloy B. The effect of aging for 200 hr at 1100, 1200, 1300 and 1500° F upon the room-temperature hardness of Hastelloy-Alloy-B welded joints is shown in Fig. 7. These hardness traverses across the welded joint indicate that hardening of both the weld metal and base plate occurs during exposure in the temperature range 1100–1500° F. This condition is the most pronounced upon aging at 1300° F, but significant hardening at 1100, 1200 and 1500° F is also evident. Aging at 1300° F appears to cause the area immediately adjacent to the weld fusion line to be particularly susceptible to hardening.

Because of the pronounced hardening of the Hastelloy-Alloy-B welded joints occurring at 1300° F, this temperature was used to determine the effect of time at the aging temperature. From the hardness profiles shown in Fig. 8, it can be seen that significant weld-metal hardening occurs in times as short as 24 hr. The hardness of the base metal and weld metal increases appreciably with increasing time at temperature until a VHN of 525 is obtained near the fusion line after 500 hr. A VHN of 275 was observed in this area in the as-welded condition.

It will be noted that the hardness traverses of the aged specimens in Figs. 7 and 8 reveal a gradual increase in base metal hardness as the weld fusion line is approached. This hardness gradient in the specimens aged at 1300° F for 200 and 500 hr occurs over a distance of 0.7 in. or greater, which is considerably wider than the conventional heat-affected zone of the weld. This condition is a result of accelerated precipitation as shown in Fig. 9. A similar panorama of the material in the as-welded condition is shown in Fig. 10.

The precipitation gradient is thought to be attributable to the presence of plastic strain in the weldment created by the repeated heating and cooling of the base

metal during the welding operation. The restraint provided by the thick hold-down plates was sufficient to inhibit free movement of the base metal, and a readily visible reduction in cross-sectional area resulted. Unpublished work at ORNL has indicated that wrought Hastelloy Alloy B containing a slight degree of cold work hardens very rapidly at these temperatures, with the amount of hardening occurring during a given time interval varying significantly with the amount of cold work.

Some hardening of the Hastelloy-Alloy-B base plate adjacent to the fusion line was also evident in the as-welded condition. This was attributed to cold work rather than to aging during welding, since two nonage-hardenable alloys, INOR-8 and Inconel, also revealed similar hardening characteristics, as is shown in Fig. 11.

Annealing of a welded joint for 1 hr at 1950° F prior to aging at 1300° F to accomplish stress relief and recrystallization eliminated the hardness gradient in the base metal, as shown in Fig. 12. The lower weld-metal hardness of the annealed-and-aged specimen was attributed partially to weld-metal homogenization occurring during the annealing operation, as well as to stress relief of the weld deposit.

Since the behavior of welds at a typical operating temperature of 1200° F was considered to be of prime importance, the effect of aging time at this temperature upon the weld-metal hardness was determined. The results are included in Fig. 13. They again indicate that extensive age-hardening occurs, although to a lesser degree than that observed at 1300° F.

Hastelloy Alloy W. The nickel-molybdenum-chromium alloy filler metal (Hastelloy Alloy W) also ages extensively in the temperature range 1100–1500° F. The influence of time at the aging temperature of 1200° F upon the room-temperature hardness of Hastelloy-Alloy-W weld metal is included in Fig. 13. It is evident that the extent of aging at this temperature is less than that noted for Hastelloy Alloy B.

INOR-8. Aging of INOR-8 weld metal at 1200° F did not result in an increase in hardness as is evident from the curve shown in Fig. 13. Traverses made on joints after aging for 200 hr at 1100, 1200, 1300 and 1500° F and for 1000 hr at 1200° F also revealed no hardening.

After 1000 hr at 1200° F, the Hastelloy Alloy B has reached a VHN of 470, the Hastelloy Alloy W has reached a VHN of 360, while the

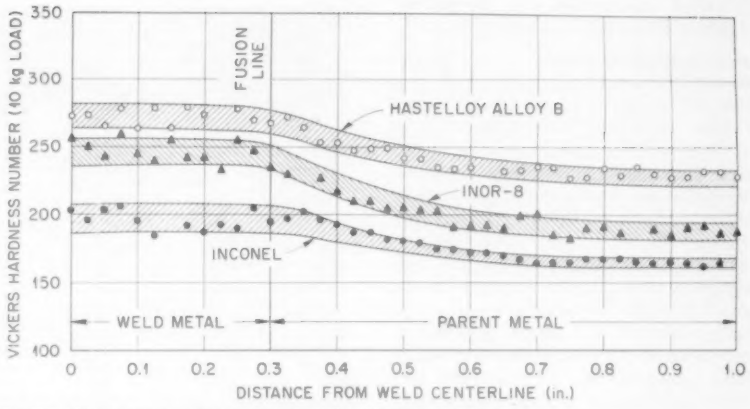


Fig. 11—Hardness traverses on Hastelloy-Alloy-B, INOR-8 and Inconel welds in as-welded condition

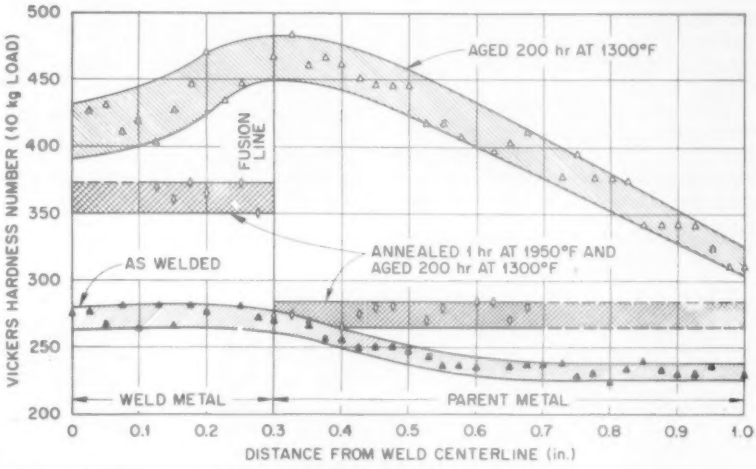


Fig. 12—Effect of annealing upon aging characteristics of Hastelloy-Alloy-B welds

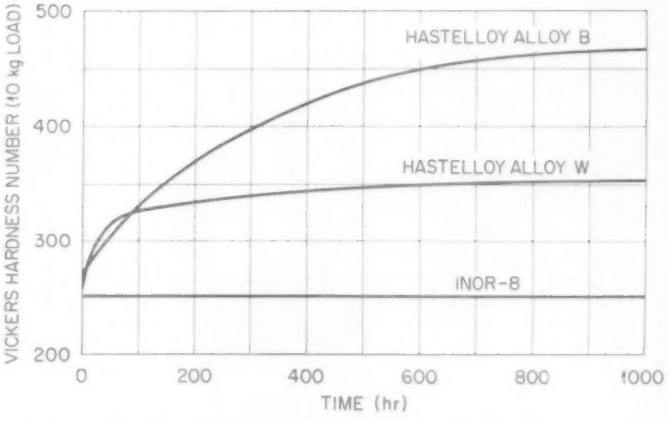


Fig. 13—Effect of aging time at 1200° F on room-temperature hardness of Hastelloy-Alloy-B, Hastelloy-Alloy-W and INOR-8 weld metal

INOR-8 maintains its as-welded VHN of 250.

Room-temperature and Elevated-temperature Tensile Studies

The influence of aging at a typical reactor operating temperature of 1200° F upon the room-temperature mechanical properties of weld metal of the three alloys is shown in Fig. 14. The tensile strengths of the age-hardenable alloys Hastelloy Alloy B and Hastelloy Alloy W increase markedly by aging for 200 hr. Slight additional increases in the strengths are evident after aging for an additional 300 hr. The room-temperature ductilities, however, continue to decrease markedly with increasing time at temperature, with the elongation of Hastelloy-Alloy-B weld metal being reduced to 3% after aging for 500 hr at 1200° F. The INOR-8 alloy, on the other hand, shows very little change in the tensile strength or the ductility upon aging for extended periods at 1200° F.

The tensile properties of the three alloys at 1200° F are shown in Fig. 15. The tensile strength of the age-hardenable alloys increases with increasing time at temperature,

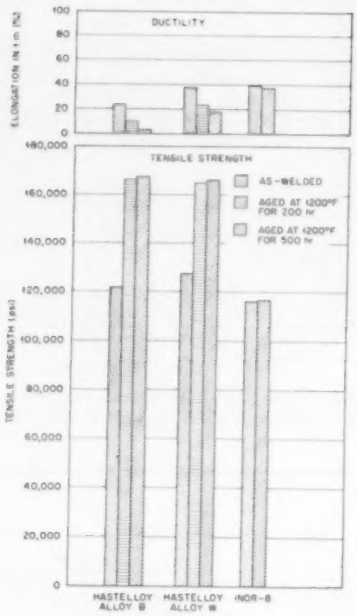


Fig. 14—Room-temperature mechanical properties of Hastelloy-Alloy-B, Hastelloy-Alloy-W and INOR-8 weld metal in the as-welded condition and after aging at 1200° F

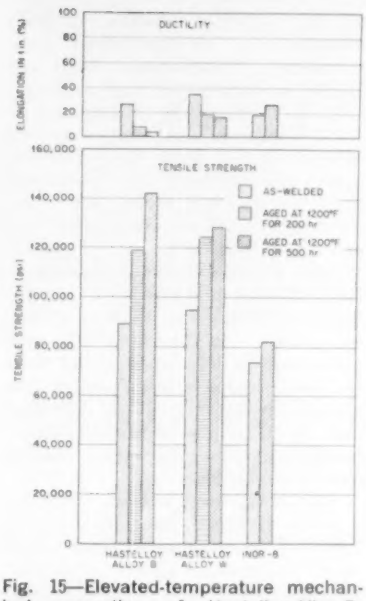


Fig. 15—Elevated-temperature mechanical properties of Hastelloy-Alloy-B, Hastelloy-Alloy-W and INOR-8 weld metal at 1200° F in the as-welded condition and after aging at 1200° F

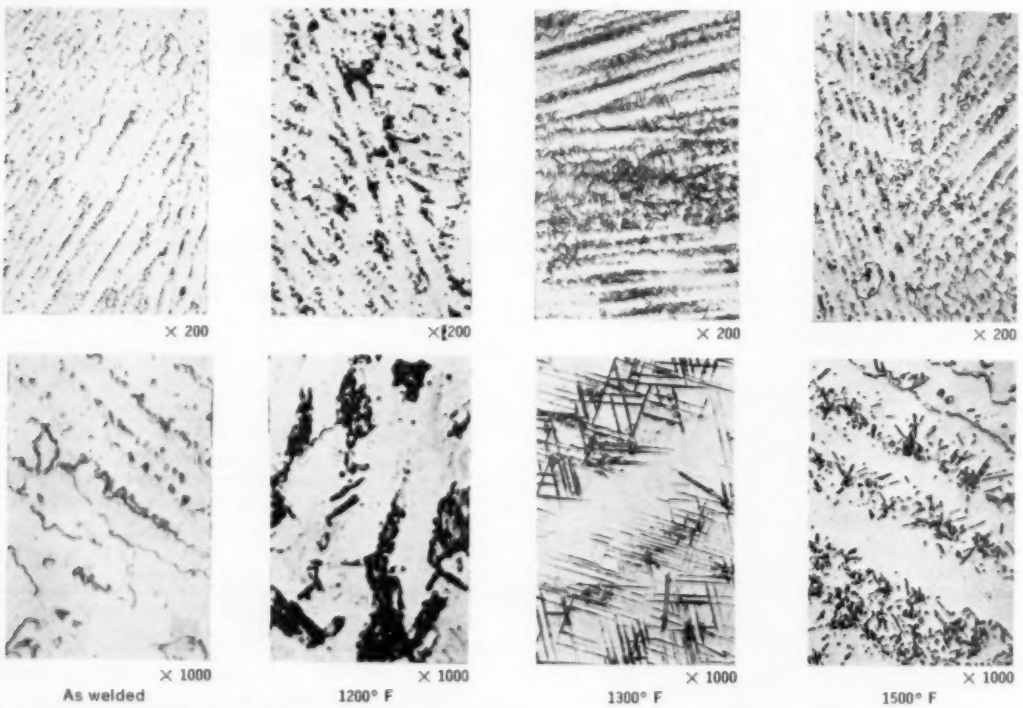


Fig. 16—Influence of aging at various temperatures for 200 hr upon the microstructure of Hastelloy-Alloy-B weld metal. Etch, Cr. Regia. (Reduced by 1/3 upon reproduction)

and the ductility decreases. Again the Hastelloy Alloy B exhibits a ductility of 3% after aging for 500 hr. INOR-8, however, exhibits an increase in ductility, probably as a result of some carbide spheroidization or redistribution.

Metallographic Studies

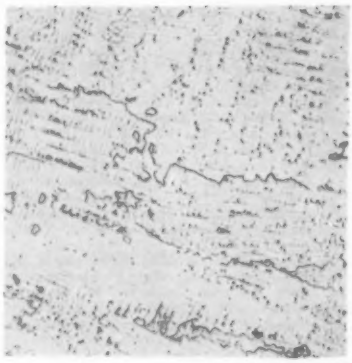
Hastelloy Alloy B. The microstructure of Hastelloy-Alloy-B weld metal in the as-welded condition exhibits the presence of carbides in the grain boundaries and between dendrites. Aging at 1200° F produces a very fine Widmänstatten-type precipitate which has tentatively been identified as the beta phase of the nickel-molybdenum binary diagram. This precipitate probably caused the extensive hardening of the material noted in the preceding discussion.

A coarser and more general Widmänstatten type of precipitation in the weld metal was noted upon aging at 1300° F. The extensive hardening of the base metal and weld metal noted upon aging at this temperature is also apparently associated with the beta phase.

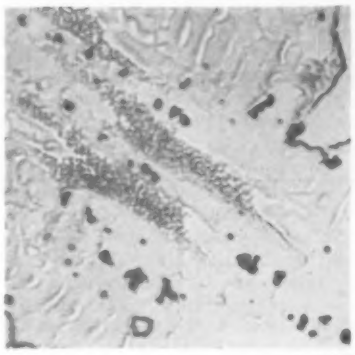
The hardening noted at 1500° F is due to the precipitation of an angular phase which, according to the nickel-molybdenum phase diagram, may be the gamma phase. A composite of the microstructures occurring from aging at these temperatures is shown at ×200 and ×1000 in Fig. 16.

Hastelloy Alloy W. The microstructure of Hastelloy-Alloy-W weld metal in the as-welded condition is shown in Fig. 17. Aging at 1200° F produced no precipitate visible under the microscope at ×1000; however, the presence of a submicroscopic precipitate is postulated in view of the significant hardening and ductility decrease noted after exposure to this temperature for extended periods. Less precipitation than that observed in Hastelloy Alloy B would be expected, since the addition of chromium to nickel-molybdenum alloys tends to suppress the formation of the beta phase.[16] Less precipitation might also be expected, since the molybdenum content of Hastelloy Alloy W is somewhat lower than that of Hastelloy Alloy B.

INOR-8. The microstructure of INOR-8 weld metal in the as-welded condition is shown in Fig. 18. The presence of extensive interdendritic and grain-boundary carbides is evident. Aging at 1200° F for times up to 1000 hr revealed no evidence of a precipitate.

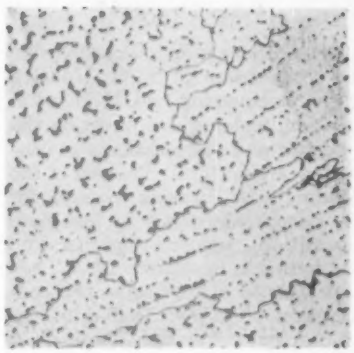


× 200

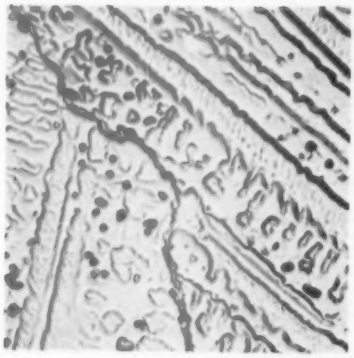


× 1000

Fig. 17—Hastelloy-Alloy-W weld metal as-welded. Etch, Cr. Regia (Reduced by 25% upon reproduction)



× 200



× 1000

Fig. 18—INOR-8 weld metal as-welded. Etch, Cr. Regia. (Reduced by 25% upon reproduction)

Conclusions

Within the limits of this investigation, the following conclusions can be drawn:

1. The commercially available nickel-molybdenum alloy Hastelloy Alloy B and the nickel-molybdenum-chromium alloy Hastelloy Alloy W are readily weldable by the inert-gas-shielded tungsten-arc process and exhibit no difficulties with regard to cracking and porosity. The room- and elevated-temperature mechanical properties of weld metal in the as-welded condition are adequate for molten-salt reactor service.

2. Hardness studies indicate that Hastelloy-Alloy-B weldments (weld metal and base-metal plate) are subject to significant age hardening during service in the temperature range 1100–1500° F, with the greatest hardening noted at 1300° F. The effect of aging at 1200° F was studied extensively and was found to increase the room- and elevated-temperature tensile strength of weld metal, while severely decreasing the ductility.

3. An increased hardening in the base metal of Hastelloy-Alloy-B weldments adjacent to the weld was attributed to the influence of residual stresses from the welding operation.

4. The precipitate observed in Hastelloy-Alloy-B welds and base plate after aging at 1300° F and below has been tentatively identified as the beta phase of the binary nickel-molybdenum phase diagram, while that at 1500° F has been tentatively identified as the gamma phase.

5. Hastelloy-Alloy-W weld metal is also subject to age hardening at elevated temperatures, but to a lesser extent at 1200° F than Hastelloy Alloy B. Age hardening raises its room- and elevated-temperature tensile strength and decreases its ductility significantly. The hardening at 1200° F is attributed to a submicroscopic precipitate.

6. A nonage-hardenable nickel-molybdenum-chromium alloy which was developed by the ORNL Metallurgy Division and designated as INOR-8 is readily weldable. The weld metal possesses acceptable mechanical properties at room temperature and at 1200° F. This alloy is now commercially available.

Acknowledgment

The authors wish to acknowledge the contribution of T. R. Housley of the Engineering and Mechanical Division, under whose direction the weld test-plate fabrication was conducted, and of R. G. Shooster of the Welding and Brazing Group, for his general assistance in test-plate fabrication, specimen preparation and hardness measurements. They also wish to acknowledge the contribution of C. W. Dollins of the Mechanical Testing Group in obtaining the mechanical property data and of L. A. Amburn of the Metallography Section for the metallographic contributions to this investigation.

References

1. *Hastelloy High-Strength, Nickel-Base, Corrosion-Resistant Alloys*, Haynes Stellite Co., pp. 6–13 (Sept. 1, 1951).

2. Chisholm, C. G., "Welding and Other Fabrication Methods for Hastelloy Alloys," THE WELDING JOURNAL, **25,** 1179–1183 (1946).

3. Culbertson, R. P., "Weldability of Wrought High-Alloy Materials," *Ibid.*, **34,** 220–230 (1955).

4. Culbertson, R. P., and Perriton, R. C., "The Welding of High-Nickel Alloys for Chemical Plant and Equipment," 1958 Annual Assembly of International Institute of Welding at Vienna (June, 1958).

5. Wilson, R. M., Jr., and Burchfield, W. F., "Nickel and High-Nickel Alloys for Pressure Vessels," THE WELDING JOURNAL, **35,** Research Suppl., 32-s to 40-s (1956).

6. *Hastelloy Corrosion-Resistant Alloys*, Haynes Stellite Co. (1957).

7. *Haynes Alloys for High-Temperature Service*, Haynes Stellite Co. (1950).

8. Lane, J. A., MacPherson, H. G., and Maslau, F., *Fluid Fuel Reactors*, Addison Wesley Publishing Co., Inc., pp. 567–697 (1958).

9. Manly, W. D., *et al.*, *Metallurgical Problems in Molten Fluoride Systems*, Paper 1990 of Second United Nations International Conference on the Peaceful Uses of Atomic Energy (September 1958).

10. Clausing, R. E., Patriarca, P., and Manly, W. D., *Aging Characteristics of Hastelloy B*, ORNL-2314 (July 1957).

11. Kennedy, C. R., and Douglas, D. A., *High-Temperature Mechanical Properties of Hastelloy B and Hastelloy W*, ORNL-2402 (November 1958).

12. *Hastelloy Corrosion-Resistant Alloys*, Haynes Stellite Co., p. 89 (1957).

13. WELDING HANDBOOK, AMERICAN WELDING SOCIETY, pp. 1125–1126 (1942).

14. *Oak Ridge National Laboratory Reactor Material Specifications*, TID-7017, pp. 141–161 (Oct. 29, 1958).

15. *Metals Handbook*, American Society for Metals, p. 1230 (1948).

16. Ellinger, F. H., "The Nickel-Molybdenum System," *Trans. Am. Soc. Metals*, **30,** 607 (1942).

17. Stoffel, D. W., and Stansbury, E. E., *A Metallographic and X-Ray Study of Nickel Base Alloys of 20–30 Per Cent Molybdenum and 13–15 Per Cent Chromium*, University of Tennessee Thesis, M.S. (1955).

18. Lundy, T. S., and Stansbury, E. E., *A Metallographic and X-Ray Study of Nickel-Base Alloys of 20–25 Per Cent Molybdenum and 3–15 Per Cent Chromium*, University of Tennessee Thesis, M.S. (1957).

BULLETIN SERIES

Requests for single copies should be sent to the

AMERICAN WELDING SOCIETY, 29 W. 39th St., New York 18, N. Y.

Requests for bulk lots of ten or more, should be sent to the

WELDING RESEARCH COUNCIL, 29 W. 39th St., New York 18, N. Y.

No. 45 **Ten Years of Progress in Pressure Vessel Research,** by F. L. Plummer, R. D. Stout, E. Wenk, Jr., and I. E. Boberg, December 1958. $1.00.

No. 46 **Observations of Strains Near Reinforced and Non-reinforced Cone-cylinder Intersections,** by Charles Kientzler and S. F. Borg; Discussion, **"Design Formulas for a Thin Cylinder with Cone Shaped Ends",** by Cyril O. Rhys, January 1959. $1.00.

No. 47 **An Experimental Investigation of Open-web Beams,** by A. A. Toprac and B. R. Cooke, February 1959. $1.00.

No. 48 **Plastic Design of Pinned-base Gable Frames,** by Robert L. Ketter, March 1959. $1.00.

No. 49 **Stresses in a Spherical Vessel from Radial Loads Acting on a Pipe; Stresses in a Spherical Vessel from External Moments Acting on a Pipe; Influence of a Reinforcing Pad on the Stresses in a Spherical Vessel Under Local Loading,** by P. P. Bijlaard, April 1959. $3.00.

No. 50 **Stresses in Spherical Vessels from Local Loads Transferred by a Pipe; Additional Data on Stresses in Cylindrical Shells Under Local Loading,** by P. P. Bijlaard, May 1959. $2.00.

No. 51 **Theoretical Stresses Near a Circular Opening in a Flat Plate, Reinforced with a Cylindrical Outlet,** by E. O. Waters; **Stresses in Contoured Openings of Pressure Vessels,** by D. E. Hardenbergh; **A Three-dimensional Photoelastic Study of Stresses Around Reinforced Outlets in Pressure Vessels,** by C. E. Taylor, N. C. Lind and J. W. Schweiker; **Unreinforced Openings in a Pressure Vessel,** by F. S. G. Williams and E. P. Auler, June 1959. $2.00.

Electron-Beam Welding

Experimental results achieved by the initial development investigation and their applications are described

BY G. BURTON, JR. AND WM. L. FRANKHOUSER

ABSTRACT. A high-voltage electron-beam welding machine with a maximum beam power of 1 kw has been operated since July 1958. With this equipment, it has been possible to make butt-joint weld penetration up to 0.250 in. in Zircaloy-2. Chemical analyses, metallography, corrosion tests and mechanical-property evaluations have revealed satisfactory properties in the Zircaloy-2 welded by this process.

The high-voltage (50 to 100 kv) electron-beam equipment has distinct advantages for extreme concentration of welding heat not realized with other processes nor with low voltage (5 to 50 kv) electron beam equipment. As a result, potential production applications are foreseen in welding fuel assemblies for the nuclear reactor industry. A second high-voltage electron-beam welding machine with a maximum beam power of 2 kw (150 kv/20 ma) has been ordered and will be used in the development of pilot production processes.

Electron-beam Welding

Historical

Since World War II, developments in rocket, missile and aircraft technology, and in nuclear-reactor engineering have resulted in a need for metals and alloys reactive with air, in all of the conventional mill shapes. As a result of the high degree of reactivity of these materials with air at elevated temperatures, melting and hot working operations have been performed in inert atmospheres or in a vacuum. Two of the better known and more fully-developed of this group of operations are vacuum-arc melting and electron-beam melting. The major advantage of these melting processes over the more conventional types is the improved properties of the cast metal which result from the lower contamination and impurity levels made possible by melting under vacuum. In the melting of Zircaloy-2 and the welding of nuclear core components from this alloy, industry has previously used inert-gas shielding atmospheres. However, the melting process has recently been altered and is now performed under vacuum with a corresponding improvement in the properties of the metal. The electron-beam welding process performed under vacuum now offers similar advantages to the welding engineer through the reduction of contamination and has even greater potential in other areas to be described in subsequent sections.

K. Steigerwald, of Carl Zeiss in West Germany, performed a welding operation with a high voltage (> 50,000 v) beam of electrons in 1950, and J. A. Stohr of the Atomic Energy Commission of France joined metals with an electron beam in 1955 and first announced his experiments in November 1957.[1] Since this latter date there has been considerable interest in the process in the United States, Great Britain and France, with the first activity in the United States at the Hanford Atomic Products Operation.[2,3] At the Westinghouse Electric Corp., Bettis Atomic Power Division (Bettis), interest was aroused in this process in November 1957 and laboratory electron-beam weld-

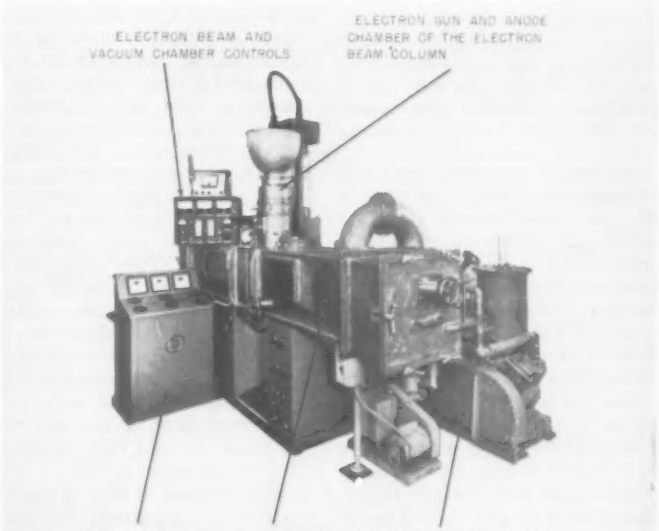

ELECTRON BEAM AND VACUUM CHAMBER CONTROLS
ELECTRON GUN AND ANODE CHAMBER OF THE ELECTRON BEAM COLUMN
HIGH VOLTAGE CONTROL CONSOLE
LEAD LINED VACUUM WELDING CHAMBER
MECHANICAL VACUUM PUMP AND 6" DIAMETER OIL DIFFUSION PUMP (NOT IN FULL VIEW)
THE ELECTRON BEAM COLUMN CONSISTS OF AN ELECTRON GUN, ELECTROSTATIC FOCUSING ELECTRODE, ANODE, TUNGSTEN ORIFICE, OPTICAL VIEWING SYSTEM, AND AN ELECTROMAGNETIC LENS. THE VACUUM CHAMBER IS 15"x15"x94" AND LINED EXTERNALLY WITH 1/8" THICK LEAD SHEET TO PROTECT THE OPERATOR FROM HARMFUL X-RADIATION GENERATED DURING WELDING

Fig. 1—One-kilowatt high-voltage electron-beam welding machine

G. BURTON, JR. is senior engineer and WM. L. FRANKHOUSER is supervising engineer at Bettis Atomic Power Div., Pittsburgh, Pa.

Paper presented at the AWS National Fall Meeting held in Detroit, Mich., September 28–Oct. 1, 1959.

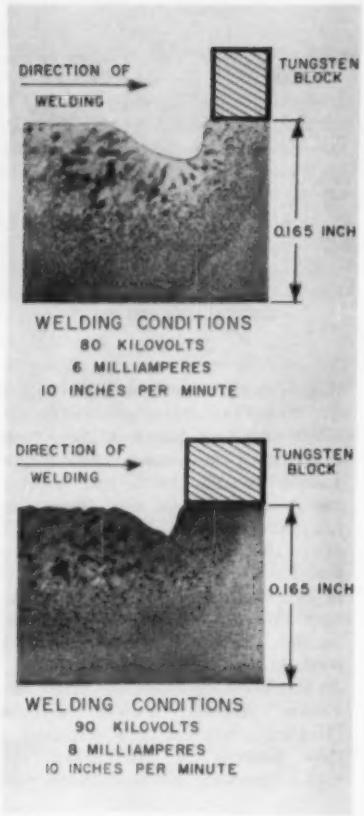


Fig. 2—Longitudinal section through electron-beam welds made in solid Zircaloy-2 showing the crater formed by intercepting the electron beam by a tungsten block during the weld traverse

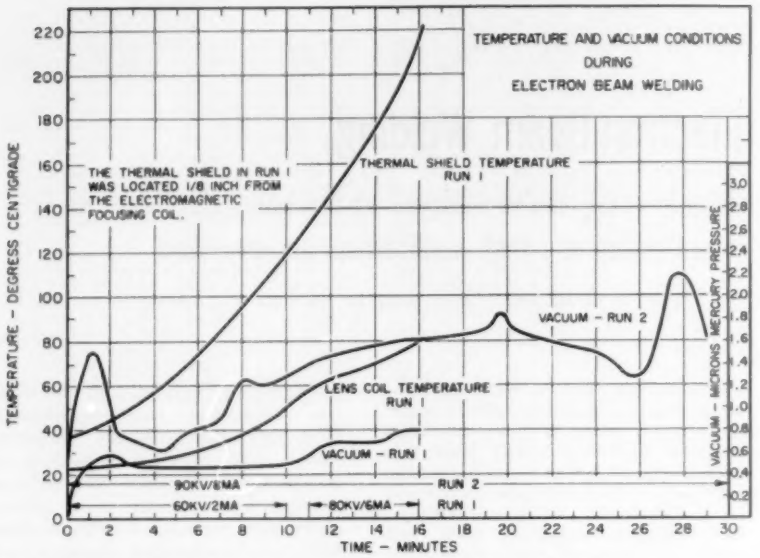

TEMPERATURE AND VACUUM CONDITIONS DURING ELECTRON BEAM WELDING
THE THERMAL SHIELD IN RUN 1 WAS LOCATED 1/8 INCH FROM THE ELECTROMAGNETIC FOCUSING COIL.
THERMAL SHIELD TEMPERATURE RUN 1
VACUUM – RUN 2
LENS COIL TEMPERATURE RUN 1
VACUUM – RUN 1
90KV/8MA
RUN 2
60KV/2MA
80KV/6MA
RUN 1
TEMPERATURE – DEGRESS CENTIGRADE
VACUUM – MICRONS MERCURY PRESSURE
TIME – MINUTES

Fig. 3—Temperature and vacuum conditions during welding with 1-kw electron-beam welding machine

ing equipment has been operated since early July 1958. The equipment was manufactured in West Germany, and differs radically from electron beam welding equipment of American manufacture in that it operates at relatively high voltages and low currents, and incorporates a precision electron optical system. Contemporary domestic equipment has been developed primarily for operation in the 5 to 50 kv and 0.1 to 0.75 amp ranges at a maximum electron-beam power of about 7.5 kw, while the high-voltage equipment operates at 50 to 100 kv at less than 0.01 amp and at a maximum beam power of 1 kw. A detailed description of the construction and operation of this high-voltage laboratory welding equipment, shown in Fig. 1, has been given in the trade literature by Burton and Matchett.[4] This article is primarily concerned with a description of the experimental results achieved by the initial developmental investigation and of their applications.

The Welding Process

Briefly, electron-beam welding consists of conversion of the kinetic energy of a high-velocity beam of electrons to heat when the electrons strike the surface of the workpiece. The thermal energy from the high-voltage stream of electrons is highly concentrated at the metal surface and is sufficient to overcome the capacity of the adjacent body to absorb it through conduction. Both melting and vaporization occur within a localized area. A conical cavity is formed at the surface as a result of the vaporization, and the molten metal around the periphery of this void flows into the cavity as the electron beam traverses the weld seam. This cavity is formed to a considerable depth below the surface on which the electrons at first impinge, as shown in Fig. 2. The photomicrograph and sketch show a longitudinal section through the center of a weld at the point of interruption of the electron beam by a block of tungsten positioned on top of the work surface. The high concentration of heat at the original surface is presumed to have produced the conical cavity which, when formed, presents a greater surface area to the electron beam and a corresponding reduction in the beam per unit area of surface in the workpiece. The heat input at the weld joint is concentrated below the workpiece surface and essentially "inside" the metal. The electrons do not pass entirely through the crevice at the joint because of the pool of molten metal which bridges this gap. It is this interpretation which is believed to explain the 2:1 depth to width ratio of the fusion zone of high-voltage electron-beam welds to be discussed subsequently. Thus it may be concluded that the high concentration of thermal energy and not the mechanical force of the accelerated electrons is responsible for the unique depth of the welds.[5]

The procedure for operating the high-voltage welding equipment consists of (1) evacuation of the chamber containing the workpiece and the electron-beam column to less than 0.03 micron mercury pressure, (2) adjustment of the filament current to obtain a predetermined standardized emission, (3) direction of the beam as nearly as possible along the central axis of the electron optical column by mechanically positioning the electron gun, (4) activation of the electromagnetic lens, and (5) electronic alignment of the electron beam with the magnetic center of the lens by adjustment of the electromagnetic deflection coils. The effect of these adjustments on the electron beam is observed by viewing the glowing spot produced by the beam on a fluorescent target. Beam voltage is held at 50 kv and a minimum current is allowed to flow. The beam is then moved to a tungsten target, and the beam voltage and current are increased to the predetermined values required for the welding operation.

In addition to the basic controls described, two other features of this welding machine are of interest. The first is a pulse-welding elec-

tronic-control component which permits the beam to be switched on and off at 1 to 3000 cps and to remain on for 0.01 to 0.00005 sec per cycle. The second feature provides oscillation of the electron beam up to $^1/_{16}$ in. either at a right angle to, or in the direction of welding. The latter feature permits poorly matched seams to be welded with a highly concentrated beam. It also allows cold filler-metal additions to be made to a weld joint, and a softening or spreading of the electron beam.

The degree of vacuum normally maintained in the welding chamber and the electron beam column is of the order of 0.03 to 5 microns mercury pressure. Typical records of the pressure inside the chamber adjacent to the work during continuous welding runs on Zircaloy-2 are presented in Fig. 3. This chart also shows the temperature attained by some of the lower components of the electron-beam column. During extended periods of welding, this heat buildup could be expected to continue until the components are destroyed. Thermal equilibrium conditions were not reached during the welding run, but the thermal shield component located just below the electromagnetic focusing lens attained a temperature of 428° F, while the magnetic lens coil itself reached approximately 177° F. For this reason a water-cooled baffle was substituted for the original thermal shield.

Weld Penetration in Zircaloy-2

The electron-beam process provides the welding engineer with an opportunity for concentration of weld heat to a degree never before attained in welding equipment. For example, it has been possible by operating at 90 kv and 5 ma to concentrate the electron beam at the workpiece to a focal spot diameter of approximately 0.010 in. This is equivalent to 5732 kw/sq in. To make an equivalent weld penetration in Zircaloy-2 by the conventional tungsten-arc inert-atmosphere-chamber welding process, 10 v and 270 amp were required, which is equivalent to only 55 kw per sq in., assuming a "spot size" of 0.250 in.. The actual energy consumed in making each of these welds was 45 and 180 w-min per inch of weld, respectively. Thus, for equivalent weld penetration in Zircaloy-2 the tungsten-arc welding process required four times the energy and melted approximately twice the volume of metal as the electron-beam welding process. Appreciable thermal energy is dissipated at the arc and into the inert shielding gas by the tungsten-arc process, while the thermal energy of the electron beam in the absence of a surrounding thermal conducting atmosphere is applied directly to the surface of the workpiece.

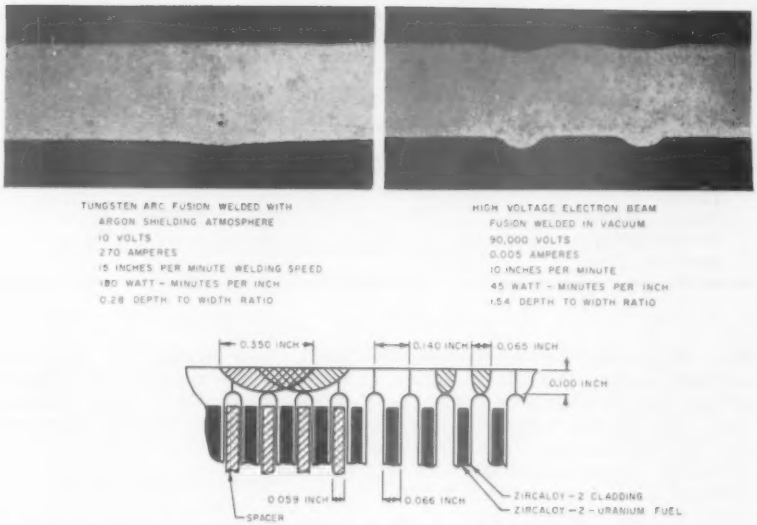


Fig. 4—Fusion-zone geometry comparison of electron-beam welds with tungsten-arc welds in typical nuclear fuel-assembly cross section.

The effect of the extreme concentration of thermal energy is also manifested three dimensionally by relatively deep weld penetration accompanied by a narrow weld-fusion zone and heat-affected zone. A comparison is made in Fig. 4 of comparable fusion-welding results obtained on standardized specimens welded by the two processes. The schematic representation in this figure of the cross section of a typical assembly of nuclear core plate-type fuel elements reveals the significance of a deep, narrow fusion-zone geometry. Total weld penetration of the joint is a design requirement for this type of fuel assembly. However, excess penetration is undesirable, especially if it extends over the heat-transfer area of the fuel. It is necessary also to restrict the width of the fusion zone to approximately one and one-half times the thickness of the fuel element at the joint in order to avoid obliteration of adjacent weld seams which are required for seam tracking. The deep penetration of electron-beam welds minimizes the amount of overpenetra-

Table 1—Weld-penetration Data

Electron-beam voltage, kv	Measurement	Electron-beam current, ma 2	4	6	8	10
50	$\bar{x}$	0.022	0.043	0.047	0.035	0.027
	s_x	0.0024	0.0015	0.0075	0.0024	0.0089
	$s_{\bar{x}}$	0.0012	0.0008	0.0037	0.0012	0.0044
60	$\bar{x}$	0.030	0.050	0.072	0.070	0.053
	s_x	0.0033	0.0187	0.0069	0.0161	0.0103
	$s_{\bar{x}}$	0.0017	0.0094	0.0034	0.0081	0.0052
70	$\bar{x}$	0.038	0.077	0.081	0.080	0.053
	s_x	0.0224	0.0050	0.0141	0.0246	0.0117
	$s_{\bar{x}}$	0.0011	0.0025	0.0071	0.0123	0.0058
80	$\bar{x}$	0.045	0.091	0.099	0.097	0.103
	s_x	0.0013	0.0103	0.0128	0.0243	0.0241
	$s_{\bar{x}}$	0.0007	0.0052	0.0064	0.0122	0.0120
90	$\bar{x}$	0.051	0.098	0.120	0.144	0.128
	s_x	0.0032	0.0064	0.0117	0.0133	0.0178
	$s_{\bar{x}}$	0.0016	0.0032	0.0058	0.0066	0.0089
100	$\bar{x}$	0.053	0.122	0.139	0.146	0.134
	s_x	0.0038	0.0104	0.0112	0.0254	0.0382
	$s_{\bar{x}}$	0.0019	0.0052	0.0056	0.0127	0.0191

The body of the table gives the arithmetic-mean weld penetration ($\bar{x}$) in inches for four welds made in 0.250-in. thick specimens of Zircaloy-2. The variability in these data is represented by s_x and $s_{\bar{x}}$, the standard deviation for individual welds and the standard deviation for the sample means, respectively.

Table 2—Chemical Composition of Electron-beam Welded Zircaloy-2 and Unwelded Base Material

	Specified requirement	Base material	Welded material
Iron, %	0.07–0.20	0.113	0.112
Chromium, %	0.05–0.15	0.112	0.106
Nickel, %	0.03–0.08	0.048	0.048
Tin, %	1.20–1.70	1.39	1.41
Oxygen, ppm	...	850	860
Nitrogen, ppm	80 (max)	20	35
Hydrogen, ppm	40 (max)	19	16

tion and avoids the obliteration of adjacent seams. With the tungsten-arc process, the seam adjacent to the last seam welded becomes covered by the fusion zone and accurate tracking becomes difficult. The lowered total energy input to the weld by the electron beam effectively reduces the shrinkage and thermal distortion to which the workpiece is subjected. Total transverse shrinkage per weld seam has been 0.010 to 0.012-in. for tungsten-arc welds and only 0.001 to 0.0015 in. for electron-beam welds.

This ability to achieve extreme concentration of thermal energy at the weld is possible only with the high-voltage-type electron-beam equipment. Three electron guns which operated between 2 and 15 kv have been tested at Bettis and several other units have been examined at other installations. In all cases, depth-to-width ratio of the weld-fusion zone has been no more than equivalent to that obtained with the tungsten-arc welding process. At the same time, consistent and uniform weld penetration in Zircaloy-2 was limited to 0.050 in. maximum, and slow welding speeds, multiple welding passes and comparatively large total energy inputs were required for low-voltage equipment; while a depth of 0.250 in. at 10 in./min welding speed has been obtained with the 1 kw high-voltage welding machine.

A survey of the complete operational range of the high-voltage 1-kw electron-beam welding machine was performed to determine the depth of weld penetration which could be achieved and to establish optimum welding conditions which would result in predictable weld penetration for use in fabrication processes. A convenient welding specimen was selected which consisted of four bars of vacuum-melted Zircaloy-2, 4 in. long x 0.500 in. wide x 0.250 in. thick. These four bars were clamped tightly together in a fixture to simulate a continuous 4-in. x 2-in. plate. Ten welds per specimen were made in the direction perpendicular to the butt joints. Subsequent to welding, the four bars were separated and the depth of weld fusion was determined at the fractured surfaces with the aid of optical measuring equipment. Six readings were obtained per weld pass, with two at each interface. Four weld passes were made at a welding speed of 15 in./min for each electron-beam power setting determined by all possible combinations of kilovoltage (50, 60, 70, 80, 90, 100) and milliamperage (2, 4, 6, 8, 10). Table 1 is a record of the arithmetic mean depth of weld fusion for each electron-beam power setting, and the estimated variance and standard deviation for the data, and the standard deviation of

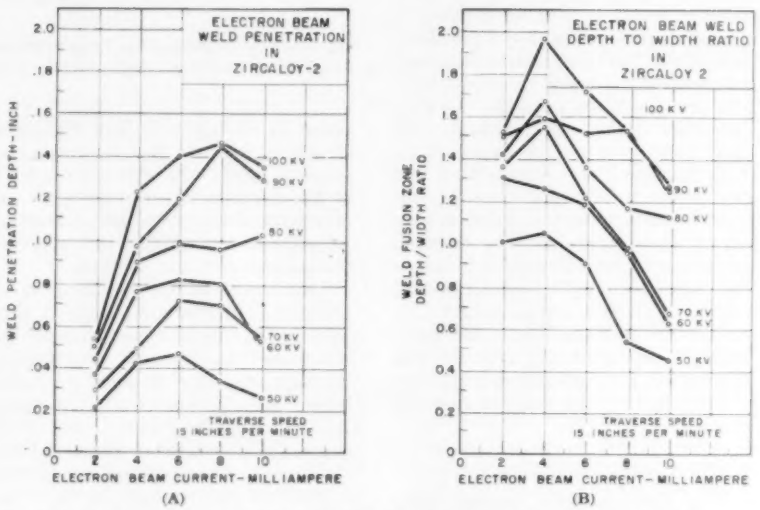


Fig. 5—Weld penetration in Zircaloy-2 with 1-kw electron-beam welding machine

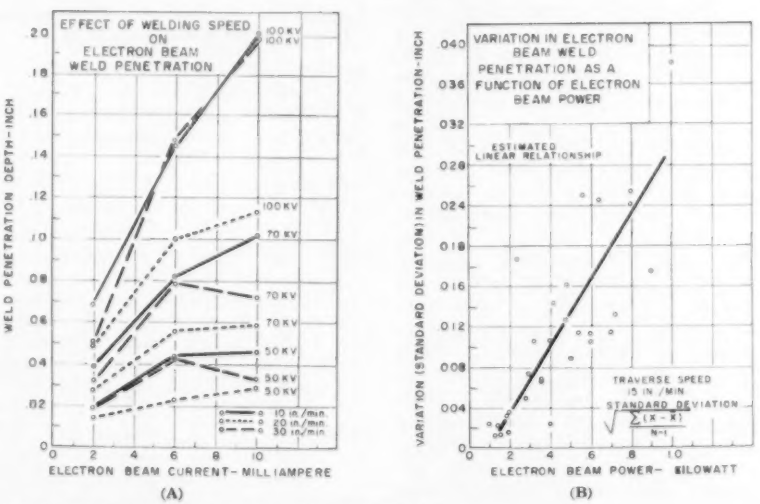


Fig. 6—Weld penetration as a function of welding speed and weld-penetration variability as a function of electron-beam power with the 1-kw electron-beam welding machine

the arithmetic means for the samples of size four. The average weld penetrations are displayed graphically in Fig. 5. On the basis of these data, it is evident that:

1. Within the useful operating range for the 1-kw welding machine, between 50 and 100 kw, weld penetration may be obtained between 0.020 and 0.150 in. at 15 in./min welding speed (see Fig. 5 A).

2. At each setting of kilovoltage there is an optimum value for the electron-beam current which results in the maximum weld depth for that particular kilovoltage. Since it is desirable to obtain a specific degree of penetration at minimum heat input (i.e., beam power) to the work, it is advantageous to operate at this value of beam current. For the complete range of kilovoltage investigated, the optimum beam current is about 5 ma at 50 kv increasing uniformly to about 8 ma at 100 kv.

3. A strong positive correlation exists between electron-beam power and reproducibility of weld penetration as indicated in Fig. 6 B. The standard deviation is a measure of the reproducibility of weld penetration for the given control settings. This correlation is further supported by the operator's experienced difficulty in setting and maintaining the control settings for the higher electron-beam powers. The exact source of this variability has not

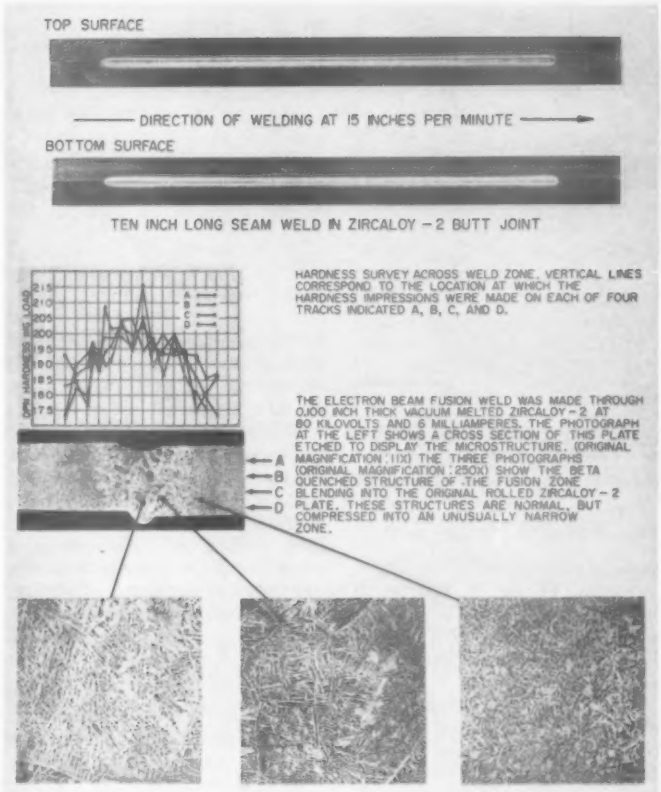

TOP SURFACE
DIRECTION OF WELDING AT 15 INCHES PER MINUTE
BOTTOM SURFACE
TEN INCH LONG SEAM WELD IN ZIRCALOY – 2 BUTT JOINT
HARDNESS SURVEY ACROSS WELD ZONE. VERTICAL LINES CORRESPOND TO THE LOCATION AT WHICH THE HARDNESS IMPRESSIONS WERE MADE ON EACH OF FOUR TRACKS INDICATED A, B, C, AND D.
THE ELECTRON BEAM FUSION WELD WAS MADE THROUGH 0.100 INCH THICK VACUUM MELTED ZIRCALOY – 2 AT 80 KILOVOLTS AND 6 MILLIAMPERES. THE PHOTOGRAPH AT THE LEFT SHOWS A CROSS SECTION OF THIS PLATE ETCHED TO DISPLAY THE MICROSTRUCTURE. (ORIGINAL MAGNIFICATION: 10X) THE THREE PHOTOGRAPHS (ORIGINAL MAGNIFICATION: 250X) SHOW THE BETA QUENCHED STRUCTURE OF THE FUSION ZONE BLENDING INTO THE ORIGINAL ROLLED ZIRCALOY – 2 PLATE. THESE STRUCTURES ARE NORMAL, BUT COMPRESSED INTO AN UNUSUALLY NARROW ZONE.
A
B
C
D

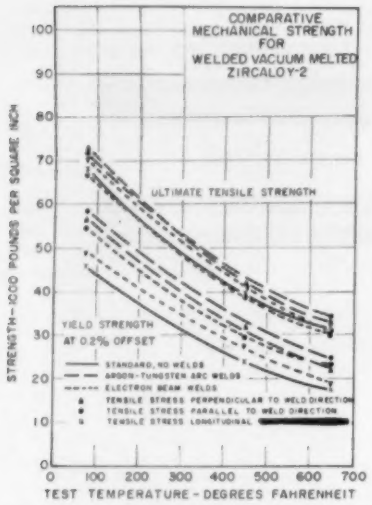
Fig. 7—Butt-type joint in Zircaloy-2 welded with the high-voltage electron beam

Table 3—Corrosion-test Data

		Testing conditions					
		680° F water test			750° F steam test		
Welding Conditions	Measurement	3 days, mg/dm²	17 days,* mg/dm²	28 days, mg/dm²	3 days, mg/dm²	14 days, mg/dm²	28 days, mg/dm²
High-voltage electron-beam welded	As-welded $\bar{x}$	9.0	19.0	23.0	19.0	36.0	54.0
	s_x	1.10	1.40	2.60	3.40	2.90	3.60
	$s_{\bar{x}}$	0.40	0.60	0.07	1.40	1.20	1.50
	Welded and pickled $\bar{x}$	14.0	21.0	26.0	18.0	34.0	36.0
	s_x	0.80	0.80	0.10	0.40	2.60	1.10
	$s_{\bar{x}}$	0.30	0.30	0.05	0.20	1.10	0.50
Tungsten-arc fusion welded in argon	As-welded $\bar{x}$	9.0	21.0	25.0	21.0	36.0	49.0
	s_x	0.90	0.60	0.50	0.90	2.10	0.90
	$s_{\bar{x}}$	0.40	0.20	0.20	0.40	0.80	0.40
	Welded and pickled $\bar{x}$	16.0	21.0	25.0	21.0	34.0	36.0
	s_x	0.60	0.80	0.90	0.60	0.50	0.40
	$s_{\bar{x}}$	0.20	0.30	0.40	0.20	0.20	0.10
Control	No welds, $\bar{x}$	14.0	19.0	25.0	20.0	36.0	39.0
	s_x	0.60	1.80	1.50	0.50	2.80	0.70
	$s_{\bar{x}}$	0.30	0.70	0.60	0.20	1.10	0.30
Standards	No welds, $\bar{x}$	12.0	20.0	23.0	19.0	33.0	36.0
	s_x	0.80	1.10	0.70	0.50	0.50	0.50
	$s_{\bar{x}}$	0.40	0.50	0.40	0.20	0.30	0.30

* These coupons were inadvertently left in test for 17 days instead of 14 days.

The body of the table gives the arithmetic mean ($\bar{x}$) gain in weight in milligrams per square decimeter for Zircaloy-2 coupon specimens subjected to the specified test conditions. Each mean is based on a sample of 6 coupons. The variability in the data is indicated by the estimated standard deviation for individual coupon weight gains (s_x) and by the estimated standard deviation for the means of samples of 6 coupons ($s_{\bar{x}}$). Control specimens were fabricated from the same material as the welded specimens and the "standards" are known weight-gain specimens used to validate the test cycle.


COMPARATIVE MECHANICAL STRENGTH FOR WELDED VACUUM MELTED ZIRCALOY-2
STRENGTH - 1000 POUNDS PER SQUARE INCH
ULTIMATE TENSILE STRENGTH
YIELD STRENGTH AT 0.2% OFFSET
STANDARD, NO WELDS
ARGON-TUNGSTEN ARC WELDS
ELECTRON BEAM WELDS
TENSILE STRESS PERPENDICULAR TO WELD DIRECTION
TENSILE STRESS PARALLEL TO WELD DIRECTION
TENSILE STRESS LONGITUDINAL
TEST TEMPERATURE - DEGREES FAHRENHEIT

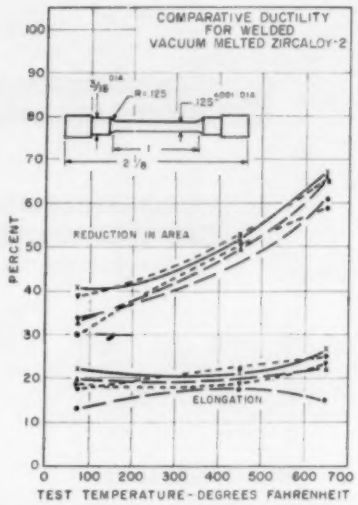


Fig. 8—Tensile properties of electron-beam and tungsten-arc welded Zircaloy-2

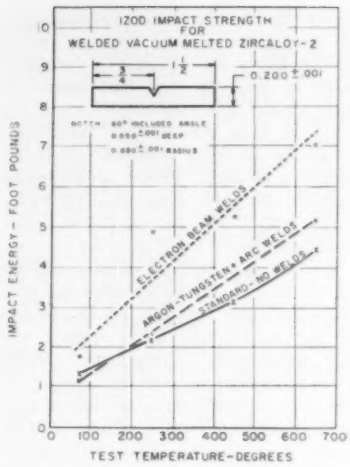

IZOD IMPACT STRENGTH FOR WELDED VACUUM MELTED ZIRCALOY-2
IMPACT ENERGY - FOOT POUNDS
ELECTRON BEAM WELDS
ARGON-TUNGSTEN ARC WELDS
STANDARD - NO WELDS
TEST TEMPERATURE - DEGREES

Fig. 9—Impact and ductility properties of electron-beam and tungsten-arc welded Zircaloy-2

yet been determined with certainty, but appears to be a functional characteristic of the laboratory model welding machine being investigated. This problem is referred to again in a later section.

4. A 2:1 ratio of depth-to-width achieved at 100 kv and 4 ma. Figure 5 B shows the relationships between the maximum width and the depth of the weld-fusion zone. A ratio of depth-to-width as great as 3:1 has been achieved in Zircaloy-2 over a small range of beam power by special adjustments in the location of the anode, cathode and cathode filament.

5. As anticipated, weld penetration is reduced by increasing welding speed, but even at 30 in./min, up to 0.100 in. depth of fusion can be readily achieved. Figure 6 A shows the general effects of increased welding speed achieved experimentally.

Although all of these penetration data were obtained on relatively short welds, work is in progress (incomplete at this writing) which shows that remarkably uniform weld penetration can be maintained over longer seam lengths, up to at least 30 in. Figure 7 shows the results obtained on butt-joint specimens 0.100 in. thick x 12 in. long where a minimum of 100% penetration was required with a minimized overpenetration and heat-affected zone. Two such specimens spaced 18 in. apart, but welded with a single pass, showed virtually identical results. The variability reported in the preceding data was the result of an inability to reproduce instrumental settings between weld passes, but within any one weld pass the penetration produced is nearly constant, varying only ± 0.005 in. from the average.

Chemistry

Alloys melted in a vacuum of the order of 1 micron mercury pressure or less have been shown to be subject to compositional changes due to the vaporization of the more volatile constituents.[6] This effect is very significant in the electron-beam melting process and must be compensated by starting with a suitably enriched base melting alloy. However, the quantity of material evaporated is dependent not only upon the vapor pressures of the elements and compounds, but also upon the time at temperature and the degree of superheating. For electron-beam welding with the 1-kw welding machine, no evidence has been found to substantiate the occurrence of a change in composition due to the welding process. Table 2 shows the chemical analysis of electron - beam - welded Zircaloy-2 and also of the adjacent unaffected base material. Allowing for normal analytical chemistry variations, no significant differences can be observed for any of the elements investigated.

Metallography and Hardness

The microstructure of typical electron-beam-welded Zircaloy-2 is similar to that of tungsten-arc fusion-welded material. Figure 7 shows a cross section through an electron-beam weld in Zircaloy-2 and also enlarged views of detail areas. The fusion zone shows fine Widmänstatten-type alpha grains formed by transformation on cooling

$$\beta \rightarrow \alpha + \beta \text{ at } 1760^\circ \text{ to } 1705^\circ \text{ F}$$
$$\alpha + \beta \rightarrow \alpha \text{ at } 1445^\circ \text{ to } 1420^\circ \text{ F}$$

from beta grains of larger size. The edge of the fusion zone has a beta-quenched structure with a very fine prior-beta grain size, indicating that this material was heated to the vicinity of the lower limit of the beta region and remained at temperature for a very short duration. Finally, the outer edge of the heat-affected zone shows an alpha + prior-beta grain structure indicating the disruptive effects of heat applied to the typical hot-worked structure of the base-plate material.

These structures are normal for welded Zircaloy-2, but evidence the fact that minimum thermal energy was applied to the butt joint to achieve fusion. In welds made with a surplus of thermal energy, the prior-beta grain size of the fusion zone is appreciably larger, due to the characteristic rapid growth of the beta grains in Zircaloy-2 with time. The narrowness of the fusion and heat-affected zones also attests to the efficient use of the applied energy.

The increase in hardness through the weld zones is attributed to a supersaturated solid-solution condition resulting from the rapid cooling of the weld.

Corrosion Resistance

Zircaloy-2 used for cladding and structural components in pressurized water-cooled and moderated nuclear reactors is usually subjected to simulated service testing to determine resistance to corrosion. This test consists of sealing specimens in an autoclave and subjecting

them to high-purity steam or water at elevated temperature and pressure. The steam test accelerates the corrosion rate and usually reveals defective material after a shorter period of testing than water. For example, 14 days at 750° F steam are equivalent in oxide formation to 84 days in 680° F water and to more than 10,000 hr of life in the PWR reactor. Corrosion results from the oxidation of the zirconium alloy, the oxygen being provided by the high-temperature water or steam. Since the ZrO_2 formed is a tightly adhering film, the oxidation rate may be measured as a function of gain in weight.

To determine whether Zircaloy-2 electron-beam-welded material retained its normal corrosion resistance, coupons machined to 1 in. x 1 1/2 in. x 0.100 in. were fabricated and then welded over at least 90% of their surface area. The lot of coupons was divided into two groups, one being placed in 680° F water and the other in 750° F steam test. The weight-gain data accumulated at 3, 14 and 28 days are recorded in Table 3 along with the expected weight gains for reactor-grade Zircaloy-2.

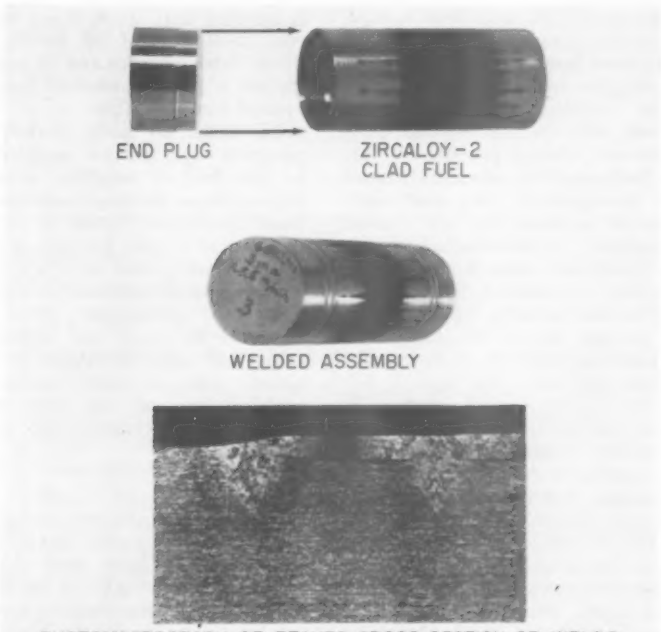
The three-day weight-gain data are of value in establishing a trend but judgment of corrosion resistance should not be made until at least 28 days of testing. The 14 (and 17) and 28-day test data revealed no significant departures for the weld metal from normally expected corrosion rates, and it can be concluded from these partially completed tests that electron-beam welded Zircaloy-2 is satisfactory for nuclear - reactor applications. These tests will be continued for a total of 128 days.

Mechanical Properties

The tensile-strength properties of welded Zircaloy-2 were investigated using subsize tensile specimens having a 1-in. gage length and an 0.125-in. gage diameter. These tensile specimens were machined from solid plates on which 100% penetration welds had been made, and were oriented both longitudinally and transversely to the welds. Reference standard specimens were machined from the plate adjacent to the welds and parallel to the rolling direction, but sufficiently distant to preclude heat effects. All specimens were annealed at 1110° F prior to testing. The testing temperatures were selected to correspond with the range of operating temperatures for pressurized water reactors. The specimens of welded material in general showed slightly higher ultimate and yield strengths and correspondingly lower reduction in area and elongation than did the hot-rolled plate material, as shown in Fig. 8. These differences are the result of the microstructural changes previously described, which were brought about by welding.

The impact-strength test specimens were also fabricated from solid-plate Zircaloy-2 in which 100% penetration welds had been made, the notch being aligned with the central axis of the weld. Specimen size was 0.200 in. sq x 1 in. long and all specimens were annealed at 1110° F prior to fracturing. The Izod test position was used for these tests.

The comparative test values obtained (see Fig. 9) revealed the electron-beam welded Zircaloy-2 to have a higher impact strength than the tungsten-arc fusion-welded material. This was probably the result of the narrow fusion zone which allowed considerable deformation to occur adjacent to the weld zone. The length direction of the standard specimens (no welds) was oriented parallel to the direction of rolling. These data are of value only on a comparative basis since total separation of the bars into two pieces occurred only in the room-temperature tests.



PHOTOMICROGRAPH OF ETCHED CROSS SECTION OF WELDS AT 25 X. THE ELECTRON BEAM FUSION WELDS ARE 0.032 INCH WIDE AND WERE MADE AT 60 KILOVOLTS, 3 MILLI-AMPERES AND 28.5 INCHES PER MINUTE WELDING SPEED.

Fig. 10—Fuel element seal welded by the high-voltage electron-beam process
(Reduced by 1/2 upon reproduction)

Process Applications

The unique characteristics of the high-voltage electron-beam welding process point to several process applications, namely: (1) the welding of refractory metals, (2) the welding of metals with relatively high thermal conductivity, (3) the welding of highly reactive metals, and (4) the making of certain "special-situation" welds not possible or inadequately performed with conventional welding processes. The first two are considered potential applications on the basis of the extreme concentration of thermal energy which makes possible the deep narrow fusion zone and narrow heat-affected zone. This reduction in size of the heat-affected zone may also be valuable in welding dissimilar metals.

The electron-beam process has already been applied to the special-situation-type welds in the nuclear industry. Metallic cladding of non-metallic fuel samples to be inserted into in-pile irradiation tests has been sealed under vacuum with the

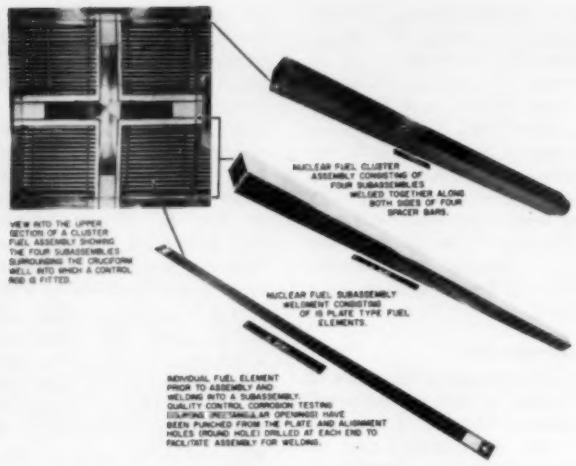

VIEW INTO THE UPPER SECTION OF A CLUSTER FUEL ASSEMBLY SHOWING THE FOUR SUBASSEMBLIES SURROUNDING THE CRUCIFORM WELL INTO WHICH A CONTROL ROD IS FITTED.
NUCLEAR FUEL CLUSTER ASSEMBLY CONSISTING OF FOUR SUBASSEMBLIES WELDED TOGETHER ALONG BOTH SIDES OF FOUR SPACER BARS.
NUCLEAR FUEL SUBASSEMBLY WELDMENT CONSISTING OF 18 PLATE TYPE FUEL ELEMENTS.
INDIVIDUAL FUEL ELEMENT PRIOR TO ASSEMBLY AND WELDING INTO A SUBASSEMBLY. QUALITY CONTROL CORROSION TESTING COUPONS (RECTANGULAR OPENINGS) HAVE BEEN PUNCHED FROM THE PLATE AND ALIGNMENT HOLES (ROUND HOLE) DRILLED AT EACH END TO FACILITATE ASSEMBLY FOR WELDING.

Fig. 11—PWR core I, seed II fuel-cluster assembly

electron beam. Because of the proximity of the weld to the fuel, which was a design requirement, it was impossible to make these seals with either low-voltage electron-beam equipment or with any conventional welding processes without danger of contaminating the cladding with fuel material. These samples required carefully controlled uniform penetration of from 0.015 to 0.020 in. with an approximately equivalent width of weld. In another special-situation-type application, a Zircaloy-2 end cap has been joined to the Zircaloy-2 cladding of a metallic-uranium fuel rod. Other fusion welding processes resulted in objectionable contamination of the cladding and weld with fuel alloy. A typical sample is shown in Fig. 10. Note the depth to width ratio of 1:1 and the narrow and uniform weld-fusion zone.

The ability to weld in vacuum has the advantage of maintaining a purity in the weld metal and correspondingly improving mechanical properties in the weld area, and thus points to potential widespread applications in the welding of reactive metals.

Welding in vacuum is effectively realized also at low voltage, but this equipment does not provide the extreme concentration of weld energy which is available with the high-voltage unit. The ultimate application anticipated is in joining assemblies of uranium-bearing fuel elements clad with zirconium-base alloys for pressurized-water nuclear reactors. This cladding alloy is extremely reactive when heated in air. Typical units as fabricated for the first core in the PWR reactor consist of plate-type fuel elements joined to form subassemblies which are quarter sections of the complete fuel-cluster assembly as shown in Fig. 11. It has not been possible until recently to weld full-size fuel subassemblies with the high-voltage laboratory equipment because of the size of the original chamber which limited weld-seam length to 4 in. With the addition of the new chamber (15 in. x 15 in. x 94 in.) shown in Fig. 1, assemblies of fuel elements up to 40 in. in length can be welded. Although this operation has not been accomplished to date, exploratory preparations have been started and satisfactory continuous seam welds have been made over significant lengths as shown in Fig. 7.

The potential advantages envisioned with the high-voltage electron-beam welding process for nuclear fuel-assembly fabrication have been extrapolated into cost estimates for subassembly and cluster fabrication. A substantial reduction in process costs is required to amortize the current high capital costs of the welding equipment if the process is to be considered competitive with the conventional welding process. By taking advantage of the use of vacuum, it appears probable that fuel elements containing oxide-corrosion films from previous corrosion tests can be welded directly into subassemblies and then into clusters without removal of the corrosion film. By taking full advantage of the overall reduced energy input to make a given depth weld and of the considerably reduced weld shrinkage and consequent distortion, it should be possible to weld subassemblies without benefit of the fuel element spacers which are ordinarily used to maintain spacing between elements during welding and removed subsequent to welding (see Fig. 4). On a specimen subassembly which was 4 in. long and contained three fuel elements welded by the electron-beam process, the average weld shrinkage per seam was 0.0015 in., while this value ordinarily averages 0.010 in. per seam with tungsten-arc fusion welding when fuel-element spacers are employed. Furthermore, it is anticipated that distortion due to the fusion welds can be maintained at a level sufficiently low such that the machining operations on subassemblies subsequent to welding will be minimized, and that straightening and sizing operations can be entirely eliminated. The ability to make deep-penetration welds with narrow fusion zones not only minimizes distortion but also eliminates the need for multiple-pass welds with filler-wire additions to achieve heavy-joint sections of the type found in fuel assemblies and in fuel-assembly structural parts. It is believed that distortion may be minimized to the degree that brackets can be welded to the ends of subassemblies during the same chamber evacuation required to weld the subassembly itself. With present techniques, considerable straightening and match machining of mating parts are required between these operations. When these ideas are incorporated into process routing charts for fuel assemblies, it appears that there is a potential cost reduction of 35 to 40% in direct labor charges and of approximately 8% in the over-all cost of a typical fuel assembly.

In order to fully pursue this program for future applications in the field of welding, a second high-voltage welding machine has been purchased which is capable of welding at 150 kv with a maximum beam power of 2 kw. This unit will be mounted on a specially designed prototype production chamber in which the largest nuclear fuel assemblies can be processed, and a pilot production-welding process for both subassemblies and clusters will be developed.

Problem Areas

Although satisfactory welds from the aspect of chemical and mechanical properties have been obtained in Zircaloy-2 with the 1-kw laboratory electron beam welding machine, at least one major problem area requires attention in the construction of a production welding machine of the future, namely, the excessive variability in weld penetration from one weld to the next due to difficulties in arriving at and maintaining machine - control settings.

This results in an inability to reproduce a specific degree of weld penetration at will. It should be noted that the 1 kw welding machine reported herein was a laboratory model made available for developmental welding applications and it is anticipated that new units will have this difficulty eliminated through the application of suitably modified controls. One possible solution would be the use of stepping switches which would adjust control settings in discrete predetermined and accurately calibrated steps. Although continuously variable adjustment would be lost, positive settings for the controls could in this way be obtained and operator error eliminated. Furthermore, the electronic circuits of the welding machine, although highly developed by German engineers, were not specifically designed for welding applications[4] and will require additional automatic stabilization to obtain the desired degree of constancy necessary for production welding. A program of mutual assistance and advice is currently in progress between the manufacturer and Bettis to produce an improved prototype production welder.

A second problem area in electron-beam welding of production parts is foreseen in the heat buildup within the workpiece during multi-pass welding on a large assembly. In tungsten-arc welding, the latent heat of fusion is transferred from the work to the surrounding inert-gas atmosphere and thence to the chamber walls where it is dissipated to the surrounding air of the room. An equilibrium temperature of 160° F inside the chamber (i.e, work and inert-gas atmosphere) is usually reached after 2 hr of welding on large nuclear-reactor assemblies and a one hour cooling period is required after completion of welding before exposure of the part to the air. It has been calculated that a similar assembly welded with an electron beam in vacuum would reach approximately 800° F and require 4 hr to cool sufficiently to be exposed to the air. Although it is possible to fill the chamber with an inert gas after completion of welding, this vitiates one of the attractive features of the electron-beam process. No entirely satisfactory solution has been reached, but calorimetric studies have been planned which are expected to reveal the exact nature of this problem and to provide a solution.

Acknowledgment

The authors wish to acknowledge contributions of other personnel at Bettis Atomic Power Division which have made it possible to publish this report. These include the guidance obtained from L. B. Prus, the technical assistance of N. A. Pollack and J. G. Landkrohn in administering the laboratory program, the engineering assistance of J. F. Smith and R. L. Matchett, the operation of the equipment by R. A. Miller and E. C. Miller and, lastly, the help in preparation of the sketches and in tabulation of the data by J. S. Yablonsky.

This work was performed and reported as a part of Contract AT-11-1-GEN-14 granted by the United States Atomic Energy Commission.

Bibliography

1. Stohr, J. S., "Electronic Welding of Metals," Fuel Elements Conference, Paris, pp. 18–23, November 1957.

2. Wyman, W. L., "High-Vacuum Electron Beam Fusion Welding," THE WELDING JOURNAL, **37** (2), Research Suppl., 49-s to 53-s (1958).

3. Wyman, W. L., and Steinkamp, W. I., "Electron Beam Vacuum Welding—Development of Process," AW-55667, Hanford Atomic Products, Operation, Richland, Wash., Apr. 8, 1958.

4. Burton, G., and Matchett, R., "Electrons Shot from Guns Make High Purity Welds," *American Machinist* **103**, No. 4, 95 Feb. 23, (1959).

5. Platte, W. N., "Electron Bombardment Welding Gun," Westinghouse Research Report, 401-FF-309-R1 (Internally Published Report)

6. Bunshah, R. F., *Vacuum Metallurgy*, Reinhold Publishing Co., New York.

Correction:

"Effects of Martensite, Bainite and Residual Stresses on Fatigue of Welds"

By R. E. Keith

In the March 1959 issue of the WELDING JOURNAL, Research Supplement, page 142-s, there appeared the following paragraph:

> The fracture behavior of cemented carbides may be an instructive case in point. These materials consist of strong hard carbide particles imbedded in a relatively soft metallic phase, or binder. Gurland[9] has shown that in such materials, containing more than about twenty vol.-% binder, the fracture path always avoids the carbide particles. Instead, the crack prefers to propagate entirely through the binder. The fatigue fracture path in a weld would probably be similar, at least for microstructures containing less than about $^3/_4$ martensite.

The figure of "20 vol.-%" was incorrect and should have been "65 vol.-%". The last sentence would then go on to read, "The fatigue fracture path in a weld would probably be similar, at least for microstructures containing less than about one-third martensite."

The Editors

Welding of Beryllium

Methods studied and the results obtained during the initial investigation of beryllium joining by various methods are presented

BY E. L. BRUNDIGE, R. S. KIRBY, G. S. HANKS AND J. M. TAUB

ABSTRACT. Satisfactory fusion welding of beryllium without the use of filler metal was found to be impractical, due to cracking either in or adjacent to the weld zone.

Acceptable welds were made using braze-welding techniques. Two processes were developed which produce consistent, reproducible joints.

One process involves the use of the inert-gas-shielded tungsten-arc welding process with pure silver as the filler metal. In the second process, the inert-gas-shielded metal-arc welding technique was employed using an aluminum-12 w/o silicon alloy as the consumable electrode. The consumable-electrode technique produced consistently sound welds if the width-to-depth ratio of the groove design provided for adequate penetration and shear strength.

Introduction

Because the metal possesses useful properties, beryllium has received consideration for applications in the aircraft, missile and reactor programs. The combination of mechanical, physical and nuclear properties provides considerable advantage for use of the metal. There exist, however, several major problems that limit application of the metal. One of the major problems, which should be solved if beryllium is to secure its maximum usefulness, is the joining of beryllium to itself and to other metals.

Some properties of the metal which limit welding methods and materials that may be used in joining beryllium are:

1. Beryllium is extremely notch sensitive: this increases the danger of cracking from uneven heating during the welding operation.

2. Beryllium appears to be somewhat hot-short when fusion welding of the metal is attempted without the use of a nonberyllium filler metal.

3. The metal oxidizes readily at 700° C. The thin, highly refractory oxide coating which forms prevents many filler materials from properly wetting the beryllium.

The toxicity of beryllium and beryllium compounds when introduced into the respiratory system and the susceptibility of some individuals to dermatitis through normal exposure require special safety precautions and equipment.

This paper presents the methods investigated and the results obtained during the initial investigation of beryllium joining by various welding methods.

E. L. BRUNDIGE, R. S. KIRBY, G. S. HANKS, and J. M. TAUB are associated with the University of California, Los Alamos Scientific Laboratory, Los Alamos, N. Mex.

Paper presented at the AWS National Fall Meeting held in Detroit, Mich., September 28-October 1, 1959.

Equipment

Standard commercial power supplies were used for all welding operations. Both alternating and direct current methods were investigated. In the initial work, a tungsten-arc torch mounted on a variable speed travel mechanism was used (see Fig. 1). The complete assembly, exclusive of power supply, was mounted in an exhaust hood to eliminate air-borne contamination by toxic dusts and vapors resulting from the welding operation. Filler wire was fed manually by the welder who wore an approved respirator during the welding operation.

Later investigations, based on this initial work, used a commercial inert-gas, tungsten-arc welding head and a commercial inert-gas-shielded metal-arc welding head which incorporated a consumable electrode as the source of filler metal. Filler metal was fed into the inert-gas-shielded tungsten arc either by a mechanical cold-wire feed or by intermittent hand feeding. Direct current power was supplied to both welding heads from a rectifier-type power supply having a maximum current output of 400 amp. Both units employed a high-frequency-arc initiating unit. The inert-gas tungsten-arc unit utilized an automatic slope control; however, tail slope during consumable-electrode welding was controlled manually. During consumable-electrode welding, the arc potential was maintained by the use of a constant-potential unit.

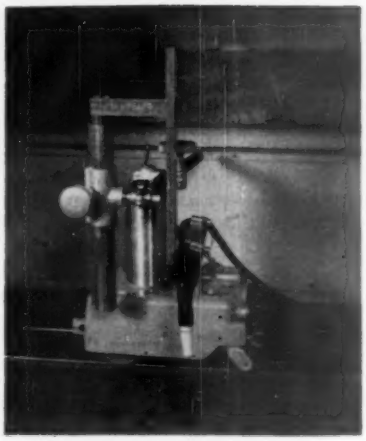


Fig. 1—Inert-gas tungsten-arc torch mounted on a variable-speed travel mechanism

Water-cooled torches were used for all work. The entire welding head assembly was mounted on a carriage which was adjustable in three perpendicular planes. The carriage was bolted to a table and enclosed in an exhaust hood. The welding fixture was also mounted in this hood. The physical setup is shown in Fig. 2.

Weld Fixture

The assemblies to be welded were mounted on a lathe-type mechanism with chucks at either end and clamped together under light pressure by tightening a handscrew. This fixture is shown in Fig. 3. The work was revolved by means of a chain drive connected through a variable speed transmission to a $^1/_3$-hp motor. In this manner, the surface speed of the work could be controlled quite accurately.

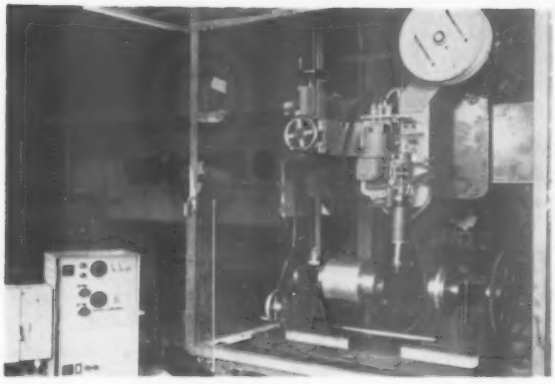


Fig. 2—Physical setup employed for the consumable-electrode welding of beryllium

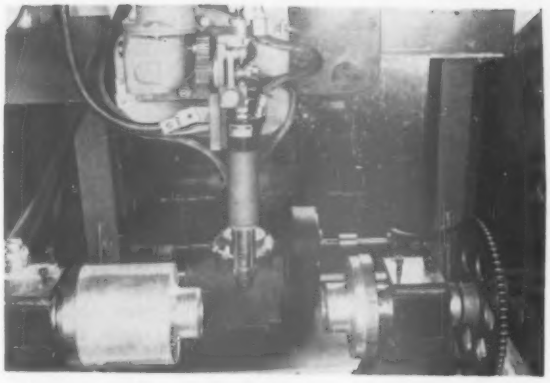


Fig. 3—Fixture for mounting beryllium assemblies for welding operation

Exhaust Hood

The hood was connected to an exhaust system employing a blower which drew an air flow of 4500 cfm. The portion of air drawn through the 4-sq ft filter in the welding hood was measured at 1400 cfm. The filter used retained 95% of 0.3-micron particles.

The welding head was installed on the permanent carriage mounted in the hood. The sides of the hood were made from 1/4-in. thick plexiglass. The front of the hood had a 30 by 30-in. opening which could be closed with a plexiglass plate having an attached welding glass to allow observation of the welding operation. The hood was closed during welding to prevent airborne beryllium contamination. The exhaust vent was closed during welding to avoid gas turbulence in the weld area.

Material

The beryllium metal was processed from powder by the vacuum-hot-pressing technique.

Specifications required that the powder be minus 200 mesh powder, with the beryllium assay not less than 98.00 w/o. Beryllium oxide content was specified as being no greater than 1.50 w/o. The required minimum density of the hot-pressed metal was 1.80 gm/cc. All beryllium components were radiographed prior to processing.

A typical chemical analysis of the beryllium metal used is as follows:

Constituent	Weight, %	Density, gm/cc
Be	99.64	1.840
BeO	0.95	1.844
Fe	0.60	
Al	0.045	
Mg	0.025	
Ni	0.010	
Cr	0.008	

Light finishing cuts were employed in the machining of all components preparatory to welding. This practice was used to eliminate rough-machined surfaces and residual stresses caused by excessive working of the metal.

Welding Investigation

Fusion Welding

As a first approach, the joining of 1/4-in. thick beryllium pieces by inert-gas-shielded tungsten-arc fusion welding was investigated. A hand welding torch mounted on a travel mechanism was used for this work. The effects of using argon, helium or argon-helium combinations with both alternating and direct current were examined. The material was welded without preheating and also by preheating to 200° C. Weld cracking occurred in all cases. Weldments made using alternating current and argon-gas shielding appeared cleaner and less oxidized than those made under the other combinations of current and shielding gases. Various types of weld joints were employed without success in an effort to eliminate cracking.

Braze Welding

The failure to fusion weld beryllium successfully led to the use of nonberyllium filler metals. First experiments were performed on a 3-in. diam beryllium test bar with weld grooves machined around the circumference at 2 in. intervals. Subsequent tests were performed on 3-in. diam hollow cylinders machined to have a weld groove; alignment of the mating components was obtained by a step joint at the center of the wall thickness. The welding groove used in both cases was a modified "V" 0.090 in. deep by 0.150 in. wide with a 0.030-in. root radius.

Because of possible corrosion of the final assembly, chemical cleaning of the area to be welded was not performed. The cleaning procedure consisted of degreasing and steel-wire brushing the weld area immediately prior to welding.

Some different filler materials (see Table 1) ranging from magnesium to silver, were tested. The only materials showing promise as cold-wire feed were pure silver, 70 w/o Ag-30 w/o Al alloy, aluminum-

Table 1—Filler Materials Tested

Filler material	Nominal composition w/o
Mg weld rod	1.2 Mn, 0.12 Ca, Bal Mg
Az-31×(A)	3.0 Al, 1.0 Zn, 0.3 Mn, Bal Mg
BAl Si-4*	12.0 Si, 88.0 Al
BAl Si-3*	10.0 Si, 4.0 Cu, 86 Al
1100 Al	99.0 Al (min)
4043 Al	5.0 Si, 95.0 Al
Be-Cu	2.0 Be, 0.35 Fe, Ni, Co, Bal Cu
OFHC Cu	99.99+ Cu
Phos Cu	0.02 P, 99.9 Cu
RCuSi-A	S, Bronze
805Al	95.0 Zn, 95.0 Al
410 S. S.	0.15 C (max), 12.5 Cr, Bal Fe
A-55 Ti	Comm. pure Ti
A-70 Ti	Comm. pure Ti
A-110-AT Ti	5.0 Al, 2.5 Sn, Bal Ti
Monel	31.5 Cu, 1.35 Fe, 0.15 Si, 0.9 Mn, 0.12 C, 66.0 Ni
FeCr	29.5 Cr, 8.0 Mn, 2.0 S, 2.0 C, 58.5 Fe
Phos Bronze	4.0 Sn, 0.08 P, 0.25 Mn,05. Fe, 95.2 Cu
3003 Al	1.2 Mn, 98.8 Al
6061 Al	1.0 Mg, 0.6 Si, 0.25 Cu, 0.25 Cr, Bal Al
Ni	Comm. pure
Ag*	99.99 + Ag
Au	99.99 Au
Ag-Mn	98.0 Ag, 2.0 Mn
Ag-Li	99.7 Ag, 0.3 Li
Ag-Mn-Li	85.0 Ag, 10.0 Mn, 5.0 Li
Ag-Al*	70.0 Ag, 30.0 Al

* These materials gave the best results.

12 w/o silicon, aluminum-10 w/o Si-4 w/o Cu, and a magnesium-aluminum alloy.

Of the four cold-wire fillers showing promise, only pure silver yielded reproducible results. Several hollow beryllium cylinders, 3-in. OD by 0.250-in. wall thickness and 6-in. OD by 0.250-in. wall thickness with closed ends, were employed as test assemblies. A $^1/_8$-in. diam stainless-steel tube was brazed in the end of one cylindrical piece to relieve any internal pressure built up during the welding operation and to provide a means of pressure testing the welded assembly. This tube was torch brazed into the beryllium using BAg-1 brazing alloy and AWS Type no. 1 flux.

The assemblies to be welded were aligned in the chucks of the welding fixture and held together under slight pressure. The joint was wire brushed and the torch and cold-wire feed mechanism positioned. Welding was accomplished under the following conditions:

Surface speed, ipm 24
Weld current, amp. . . . . 240 DC-SP
Voltage, v 16
Shielding-gas flow . . . . . 30 cfh He, 50 cfh Ar
Wire-feed speed . . . . . Intermittent manual
Number of passes 2

The six-in. diam assemblies were hydrostatically tested to rupture. Rupture occurred at an average pressure of 1550 psig, partially in shear and partially in tension. Stress at rupture, calculated for tensile failure, was 14,800 psi.

In an effort to accomplish braze welding of beryllium with a filler material having a density which more nearly approached that of beryllium, inert-gas-shielded tungsten-arc welding procedures using a cold-wire feed were discontinued.

Consumable-Electrode Welding

The low-density filler materials, which showed some indication of success with cold-wire feed techniques, were tried as consumable-electrode wire. The same joint configuration was used for this welding procedure as had been used earlier.

The use of an aluminum-silicon alloy as filler metal in the joining of beryllium had been investigated earlier.* Both BAlSi-3 and BAlSi-4 aluminum alloys had been tried.

The BAlSi-3 alloy as the consumable electrode was tried first. Welding was performed under the following conditions:

Filler material, in. diam . . . . . $^1/_{16}$ BAlSi-3 Al alloy
Welding current, amp . . . 180DC-RP
Welding voltage 30
Surface speed, ipm 28
Wire-feed speed, ipm 178
Shielding-gas flow, cfh He 150

At current levels below 150 amp, fine metal-spray transfer from the electrode to the beryllium did not occur. The metal transferred through an unstable arc in globular form. Very little penetration was obtained. Using higher currents and voltages, and a manual method of tail slope, the weld bead was smoother and flatter with greater penetration. Some porosity was encountered.

Further tests using BAlSi-4 aluminum alloy indicated that welding conditions and results were comparable with those obtained using BAlSi-3 aluminum alloy. Since BAlSi-4 alloy was considered to be the more corrosion resistant, all subsequent work was done using this alloy.

Satisfactory weldments were obtained using the $^1/_{16}$-in. diam BAlSi-4 alloy wire with the groove design illustrated in Fig. 4. Weld conditions were as follows:

Welding current, amp. 200 DC-RP
Welding voltage . . . . . ~30
Surface speed, ipm 28
Wire-feed speed, ipm 180
Shielding-gas flow, cfh He 150
Tail slope . . . . . Manual
Number of passes 2

Welding conditions were varied in an effort to eliminate the need of a second pass and to produce better weld penetration. Final weld conditions were as follows:

Welding current, amp . . . 310 DC-RP
Filler material, in. diam . . . . . $^1/_{16}$ BAlSi-4 alloy wire
Welding voltage 32
Surface speed, ipm . . . . . ~28
Wire-feed speed, ipm 240
Shielding-gas flow, cfh He 55
Number of passes 1
Slope control . . . . . Manual

These conditions resulted in reproducible welds which approached the strength of the base metal. Figure 5 shows a weld which ruptured partially in the weld and partially in the base metal. This weld exhibited a tensile strength of approximately 20,000 psi.

Other welds were made employing magnesium or magnesium alloys as the consumable electrode. Because magnesium and its alloys have a tendency to oxidize and burn readily, an inert-gas shield was maintained around the entire weld area during the welding operation. This shield protected both the magnesium and beryllium from oxidation. Welds were made using straight consumable-electrode welding and a preheating procedure. Preheating seemed to be beneficial. In all cases the welds appeared to be sound, but bonding to the beryllium was very poor. The best welds were produced using 300 amp, a wire speed of about 500 ipm, and argon shielding. The wire used for all consumable-electrode welding was $^1/_{16}$ in. diam.

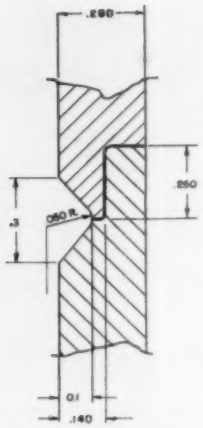


Fig. 4—Groove design employed for the successful welding of beryllium cylinders using aluminum-silicon alloy and pure silver as filler metal

Metallography

Metallographic examination of weldments made using the tungsten-arc, inert-gas welding method and pure silver as the filler metal indicated diffusion and alloying between the beryllium and silver, Fig. 6. Excellent bonding was obtained along the edge of the groove, Fig. 7. The silver had also penetrated into the step of the joint, providing additional joint strength.

The magnesium welds all showed poor and intermittent bonding.

Figures 8 and 9 are photomicrographs of two different areas at the weld metal-beryllium interface of a BAlSi-4 aluminum-alloy weld.

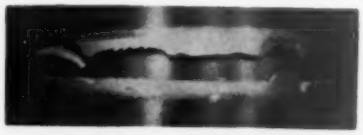


Fig. 5—Beryllium weld on cylinder using aluminum-silicon filler metal which ruptured partially in the weld and partially in the base metal. Weld strength approximately 20,000 psi

* Martin, Monroe and Voldrich, "Welding & Brazing of Be to Itself & Other Metals," BMI-836, May 28, 1953.

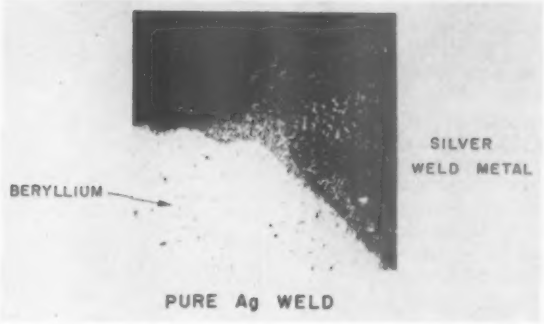


Fig. 6—Beryllium weld using pure silver as filler metal showing diffusion and alloying between the beryllium and silver

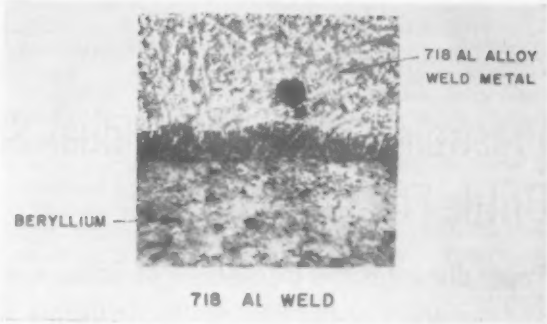


Fig. 8—Beryllium weld using 718 aluminum-silicon welding alloy showing a well-defined alloy layer between the beryllium and the weld metal

Figure 8 shows that well-defined alloying has occurred between the beryllium and the aluminum alloy. Figure 9 illustrates an area in which the filler metal appears to have penetrated between the beryllium grains rather than to have alloyed with the beryllium metal. Although this bond produced a leak-tight assembly, the joint strength should be lower than one with a structure like that shown in Fig. 7. Porosity is evident in both sections.

Examination of the rupture area of tested welds indicated that properly produced sound welds would rupture through the center of the weld metal and along the bonding area of the groove.

Conclusions

1. The notch sensitivity of beryllium must be considered in the joint design for welding. No sharp corners should be permitted and all mating edges should be rounded. Machine tool marks may initiate cracking. Light finishing machine cuts on assemblies for welding are essential.

2. Discontinuities occurring in a braze weld at the bond line can cause cracks to propagate.

3. Fusion welding of beryllium seems impractical unless it can be achieved through electron-beam methods. Beryllium wire is difficult, if not impossible to obtain.

4. Of the materials tried as filler metals in braze welding, pure silver and aluminum-silicon alloys produced satisfactory weldments. Pure silver works best when used as a cold feed in the inert-gas-shielded tungsten-arc process; the aluminum silicon alloys work best in the consumable-electrode process.

5. Wire-feed speeds in excess of 500 ipm would be necessary to evaluate fully magnesium alloys for braze-weld usage.

6. The weld-groove design should have a width-to-depth ratio of 3:1 for consumable-electrode welding to allow full penetration and adequate joint shear strength.

7. Welding currents of 180 to 200 amp DC-RP produce sound, leak-tight welds but require 2 passes to fill the groove. The weld may be completed in one pass using 300 or more amp DC-RP.

8. Braze welds which are as strong or stronger than the base metal can be produced using silver with the tungsten-arc process, or aluminum-silicon alloy and the consumable-electrode process.

9. The consumable-electrode process is consistent enough so that the joint strength can be calculated fairly accurately when the 3:1 width-to-depth groove ratio is employed.

10. Porosity is a problem in the consumable-electrode process when using aluminum-silicon alloys.

11. Special machining practices employing light finishing cuts are more necessary for the inert-gas-shielded tungsten-arc process than for the inert-gas-shielded metal-arc process to prevent stress cracking of the beryllium. Stresses set up by the concentrated heating at the weld area are more severe when using the tungsten-arc process.

12. The effect of impurities in the beryllium metal on the ductility are not known.

Acknowledgment

The authors wish to acknowledge the valuable assistance of the following persons who were instrumental in helping to develop the technique for the welding of beryllium: D. D. Bowdish, T. L. Crisler, D. T. Doll, T. I. Jones and L. O. Rickerson. All personnel are employed by the Los Alamos Scientific Laboratory, Los Alamos, N. Mex.

Fig. 7—Excellent bonding obtained welding beryllium using pure silver as the filler metal

Fig. 9—Beryllium weld using 718 aluminum-silicon welding alloy illustrating area in which filler metal penetrated between the beryllium grains rather than alloying with the beryllium metal. Porosity is evident

Prestrain, Size and Residual Stresses in Static Brittle-Fracture Initiation

Paper discusses the mechanism of fracture initiation and the effect of the previous strain history as they appear in the light of the results achieved in test program

BY C. MYLONAS

ABSTRACT. The concept of exhaustion of ductility used in the explanation of the mechanism of static brittle-fracture initiation has led to the achievement of the first laboratory fractures of unwelded steel plates under central static loading at average net stress as low as 12% of virgin yield. The same concept and considerations of required vs. existing ductility provide a rational approach for the explanation of prestrain and of size effect in brittle fracture. Similarly they lead to a clear qualitative assessment of the varying influence of residual stresses and show that the usual localized residual stresses have little if any importance in normal structural steels.

Introduction

The subject of the static initiation of brittle fracture in steel plate as a result of an exhaustion of ductility by prestraining has been reported in previous publications[1-3]. Complete fractures of notched plates of an unwelded rimmed steel subjected to static central tension have been achieved at average stress as low as 12% of virgin yield. Characteristic is the development of arrested cracks at net stress levels between 9 and 30% of virgin yield in all recent tests. These spectacular failures are the first really "brittle" static fractures ever achieved in the laboratory with unwelded steel which, in its virgin state, would not fracture before yield stress was exceeded over the whole net section and general yielding occurred. They are quite distinct from all the earlier tests in static central loading, in which general yielding preceded fracture. On the contrary, they are very similar to actual in-service fractures, not only because of the small stress level at which they occur, but also the absence of visible signs of plastic deformation. These controlled low-net-stress static initiations of fracture make it possible to study, in the laboratory, the influence of various factors on brittle fracture without the obscuring effect of the ceiling of general yielding. The purpose of this paper is to discuss the mechanism of fracture initiation and the effect of the previous strain history as they appear in the light of the achieved results. In addition, consideration is given to the possible effect of residual stresses which have frequently been accepted as an important factor in brittle fracture because of their intensity. As will be seen, the concepts used in explaining static fracture provide a rational approach to the problems of residual stresses and of the size effect. The sensitive test of low-net-stress level at the initiation of brittle fracture is used to study these problems experimentally.

General Concepts

The concepts, criteria and methods which led to such low static fractures are simple.[1-3] It is well known from actual fractures and from experiment that a crack, once started, can propagate at high speed at nominal stress levels considerably smaller than yield and lower than the nominal stress levels present in other successfully operating structures. On the contrary, it was not generally found possible to reproduce the static brittle initiation of fracture in the great number of earlier laboratory tests. Contrary to the elementary Griffith-type theories of fracture, symmetrically notched plates of sound steel having even the longest and sharpest cracks and temperatures below brittle transition were not found to fracture in central static loading before the average stress over the *net* section reached yield level and appreciable plastic deformation occurred. An exceptionally severe impact at a notch, or an artificially highly embrittled area fracturing first was needed in order to start a crack at a low level of applied stress. However, at least in a few clear-cut cases, the initiation of actual in-service fractures occurred at over-all stresses well below yield.[4] Strong evidence exists that the nominal stresses were low in many service failures, and the results of the present tests show that such low-stress fracture initiations are possible under conditions similar to those in actual structures.

The distinct relation appearing between brittleness in crack initiation and smallness of net stress can be easily explained in terms of the magnitude of the plastic strains. The stress concentration at the sharp notch gives rise to high stresses and to local yielding even at very low applied loads. The distribution of the plastic strains near the root of the notch is not known. At the root itself there is a singularity which complicates all arguments. However if the sharp notch is taken as the limit of a notch with gradually diminishing radius at its tip, it will be agreed that at all points, including the root itself, the strains at large loads will be larger than at low loads. When the section flow limit is reached (for our plates approximately average net yield stress) the strains would increase indefinitely if the material was perfectly plastic. In a strain-hardening material, the transition

C. MYLONAS is Associate Professor, Division of Engineering, Brown University, Providence, R. I. The results presented in this paper were obtained in the course of research sponsored by the Ship Structure Committee under contract NObs 65917 with the Bureau of Ships, Department of the Navy.

Paper presented at AWS 40th Annual Meeting held in Chicago, Ill., Apr. 6-10, 1959.

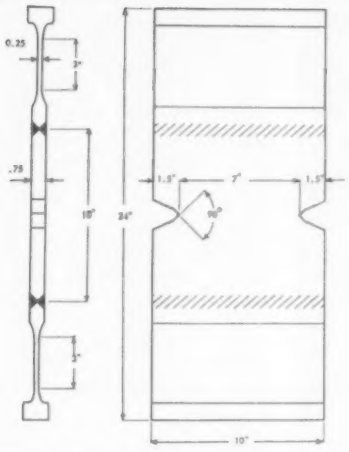


Fig. 1—Ten-inch test plate with plastic hinges

from rather small at low stress to very large when the whole section yields must be more gradual than with a perfectly plastic material. How gradual cannot be said when not only is the strain hardening law unknown but no analytical solution exists even for the rounded notch in a plate of finite thickness when the material is perfectly plastic. There may be differences of opinion on the relative magnitude of the strains but there is no doubt that the strains continuously increase with increasing load. Thus the net stress level is an indication of the magnitude of the strains. Accordingly, fractures starting at low net stress occur at lower strains than fractures starting at high net stress. Conversely, fractures showing brittleness at the point of initiation demonstrate an inability of the steel to undergo the smaller plastic deformations required at low-net-stress levels. The visible signs of plastic deformation in plates which fracture at the flow limit, as compared to the "brittle" appearance of the low-stress-level fractures are proof enough of this conclusion. Consequently *the smallness of the average net stress at fracture* is an obvious indication and adequate *criterion of brittleness during initiation*.

Since even the poorest virgin structural steels, loaded statically under the worst conditions of stress concentration and at temperatures below brittle transition, were found to have all the necessary ductility to fracture only at net average stress of yield level, it must be concluded that some additional effect produced during fabrication or service could embrittle the steel, i.e., could sufficiently reduce the original ductility for the type of stressing and constraint occurring near the notch so as to make the large strains needed at high loads impossible, and so permit low-net-stress fractures. This is referred to as an *exhaustion of ductility* in the region of the notch roots.

Object and Description of the Tests

The first object of the present work was to overcome the shortcomings of all the early tests and to reproduce consistently in the laboratory true "brittle" initiations of fracture under central static load-

Table 1—Brittle-fracture Tests of 10-In.-wide Plates with Machined Notches Prestrained in Compression After Notching

Plate	Avg. face compr. 1 in. at root of notch,[a] 10^3 in.	Avg. net compr. stress, psi	Test temperature, ° F	Avg. net tension: Maximum applied[b] Psi	Avg. net tension: Maximum applied[b] Virgin yield, %	Avg. net tension: At significant crack, % of virgin yield	Crack length or thumbnail (th), inches
14M	44–40	38,100	−9	14,400	39	12; 39[c]	3 1/4 (th.)
14N	20–15	35,200	−2	30,600	97	16, 60; 87	.....
14O	26–30	36,600	−10	>31,400	>95	14; 14; 40	.....
14P	33–34	37,300	−10	26,600	81	.....	.....
14Q	24–22	35,800	−9	>29,500	>89	9; 28;[c] 81	None at 28%; 1/2—3/16 at end
14R	23–3	33,400	−9	>25,700	78	12; 52	.....
14S	35–39	38,100	−9	28,700	87	17;[c] 34[c]	1 (th.)
14T	14–1	29,500	−9	>30,300	>92	9	3/8—0 at end
16A	41–35	38,100	−12	>28,600	>87	14; 58[c]	1/16—0 at end
16B	45	38,100	−8	>28,600	>87	19;[c] 37[c]	3/4—0 at 37%
16C	43	38,100	−10	>28,600	>87	12;[c] 28; 43;[c] 62	1/2—0 at end
16D	44–45	38,100	−8	>17,600	>54	19;[c] 54[c]	3/8—0, 19%; 3/8—1/2 at 54%
16G	36–38	38,100	−6	>25,000	>75[d]	17;[c] 43[c]	3/4—1/8 at end
16H	40–38	38,100	−10	25,100	76	17; 39[c]	1/2—1/8 at 39%; 1 (th.)
16I	46–48	38,100	−10	>28,600	>87	17; 39	None at 17%; 3/16—1/16 at end
16K	26–20	35,200	−12	25,700	78	21;[c] 46[c]	None at 21%; 1/2—1/3 at 46%; 2 th
16L	29–39	36,200	−13	17,300	52	12	None at 12%
17A	45–45	38,100	−9	25,300	77	26; 36[c]	1/4—0 at 36%
17B	43–41	38,100	−12	18,600	56	19; 25[c]	None at 19 or 25%
17E	32–37	38,100	−11	16,700	51	10; 16, 34	None at 10; 16; 34%
17F	42–46	38,100	−9	18,600	56	12; 19, 44[c]	.....
17G	46–46	38,100	−10	27,800	84	14; 27,[c] 79[c]	3/8—0 at 27%
17L	47–46	38,100	−8	25,400	77	17;[c] 54	1/4—0 at 17%
17M	50–45	38,100	−10	29,000	88	17;[c] 43	1/4—0 at 17%
17N	58–58	38,100	−10	24,200	73	24; 24; 46; 58	None at 72%
18O	55–55	38,100	−9	16,200	49	.....	.....
18P	44–45	38,100	−9	38,000	12	.....	.....
18Q	48–40	38,100	−2	17,100	52	17; 22	.....
18R	42–41	38,100	−8	22,100	67	.....	.....
18S	41–42	38,100	−1	>28,600	>87	.....	1/16—1/4 at end
18T	46–42	38,100	−6	14,700	45	.....	.....
18U	36–30	38,100	0	>26,700	>81	9; 21; 6	.....
18X	58–56	38,100	−9	>28,600	>87	.....	.....

[a] First number for side of crack initiation.
[b] Stress at fracture unless preceded by > signifying that no complete fracture occurred.
[c] Louder noise.
[d] Hinge failure.

Table 2—Various Control Tests with 10-in. Machine-notched Plates

Plate	Avg. face compr. 1 in. at root of notch, 10^3 in.	Avg. net compr. stress, psi	Test temperature, ° F	Avg. net tension Max applied Psi	Virgin yield, %	Details	
C10	None	None	−7	33,000	110	Virgin yield, 30,000 psi	No fracture
D10	None	None	−9	33,000	110		
I10	...	Buckled	−7	33,000	110		
14K	...	...	−11	31,800	96	Welds at notch roots	Not the slightest cracking noise or visible crack
14L	...	...	−10	31,800	96		
17C	40–41	38,100	−11	28,600	87	0.1-in. radius at notch roots	
17D	42–43	38,100	−8	28,600	87		
17I	55–57	38,100	−8	25,500	77	Internal notch	
17J	57–57	38,100	−7	25,500	77		
17K	57–57	38,100	−10	25,500	77		

ing. The way to achieve this would be to exhaust the virgin ductility of the steel. To increase the chances of success, a $^3/_4$-in. rimmed pedigree steel "E" of high brittle-transition range was chosen (typical composition and properties are given in Refs. 2 and 3). Various methods of damaging the steel were tried. The most efficacious was to prestrain machine-notched plates in the direction which would produce compression of the notch roots. Subsequently, the plates were tested in tension at a temperature of −5 to −14° F. The plates as tested are shown in Fig. 1. The central 10-in. square plate was first notched by milling on the lateral sides and was symmetrically beveled on the top and bottom edges. It was then clamped between heavier plates which prevented buckling and was subjected to compression on the beveled edges. The large deformation of the thin beveled edges ensured reasonably uniform loading in compression. Next, the prestrained plate was welded to special heads which would yield under tension so as to eliminate appreciable eccentricity of loading,[3] was covered with foamed plastic insulation and, with thermocouples fixed at several points, was cooled to about −18° F in a freezer. The T-heads of the test plate easily dovetailed in special pulling heads fitted on the testing machine so that the plate could be ready for testing about a minute after its removal from the freezer. The loading was started at an initial rate of about 50,000 psi per minute. The rate slowed appreciably when the hinges started yielding.

Test Results, Effect of Prestrain

The results were remarkable. Most prestrained plates fractured at a low-net-stress level, the lowest at 12% of virgin yield. Some results have already been given in Ref. 3, Table 2. Over 30 new tests and some control tests are included in Tables 1 and 2. In Fig. 2, the average net stress at fracture of all tests, or the highest applied stress when fracture did not occur, are plotted against the prestrain in inches as measured over a 1-in. length across the root of the notch from which complete fracture started. Although Fig. 2 shows a general trend to lower stress fractures for high prestrains, yet it describes only part of the results because all prestrained plates developed arrested cracks at extremely low net stress, usually between 9 and 30% of virgin yield. These cracks were observed on all prestrained plates, those which fractured as well as those which did not. They were distinctly heard during loading, and were often observed by stopping the loading, removing the insulation and examining the notch roots. Figure 3a–d shows such cracks on steel plates with ground faces which were not carried to ultimate failure. The brittleness at the point of initiation of the fracture is in clear contrast with the plastic deformation at the point of arrest. At the moment of formation of the cracks, the dimples at the points of arrest were much smaller but still visible. They were greatly accentuated during subsequent increase of the load. The last two columns of Table 1 give the average net stress at the moment when cracking was heard, and also show that such noises were often, but not always, accompanied by visible cracks and by a thumbnail on the fracture surface as shown in Fig. 4a–c. It should be noted that these cracks start under static conditions at low loads and at the relative bluntness of the sharpest possible milled 90-deg notch; that they are arrested at a greater depth and root sharpness; and that frequently they do not restart even at loads producing general yielding of the section. The result is totally contrary to the elementary energy theories of fracture of the Griffith type, which postulate an average stress at fracture inversely propor-

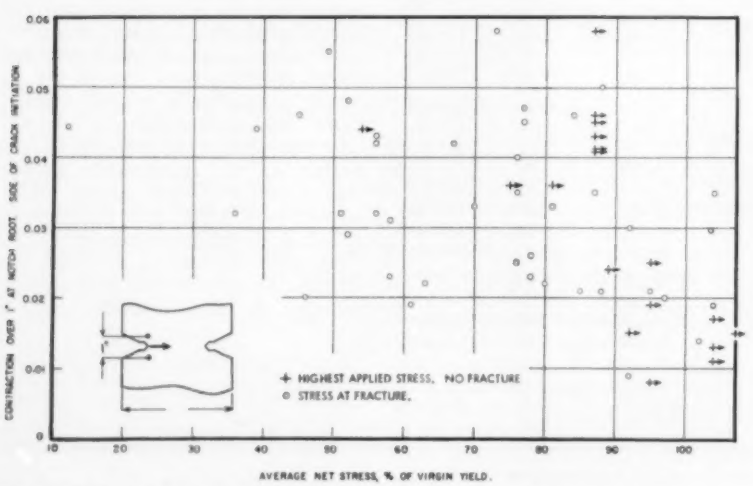
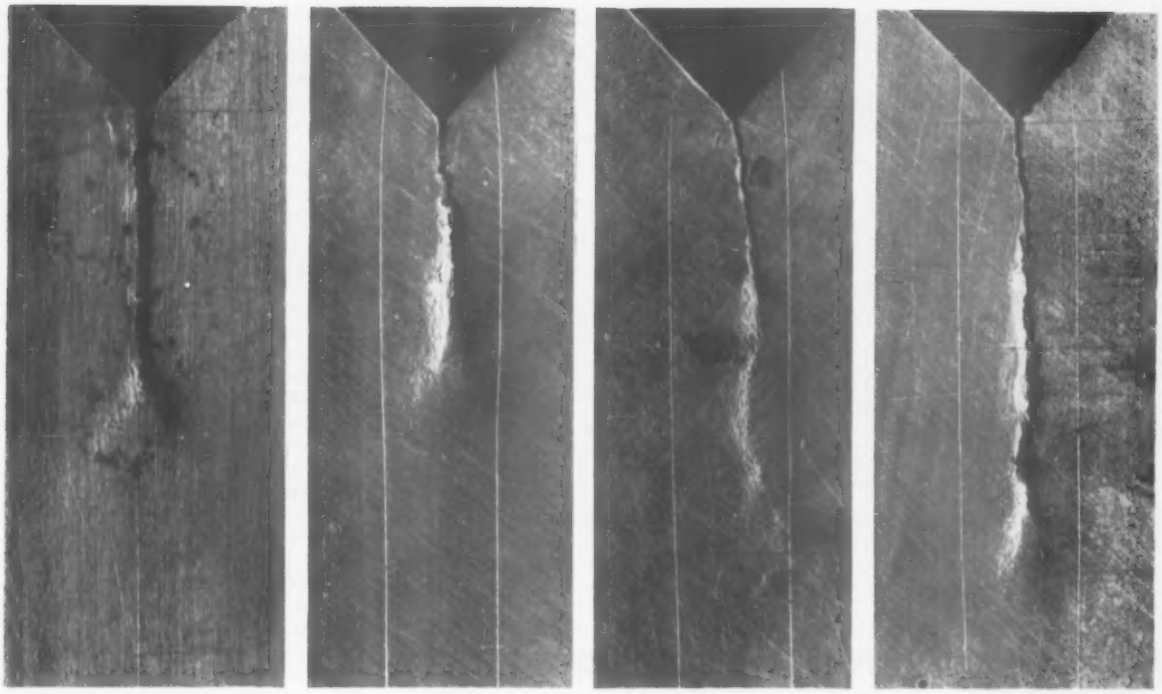
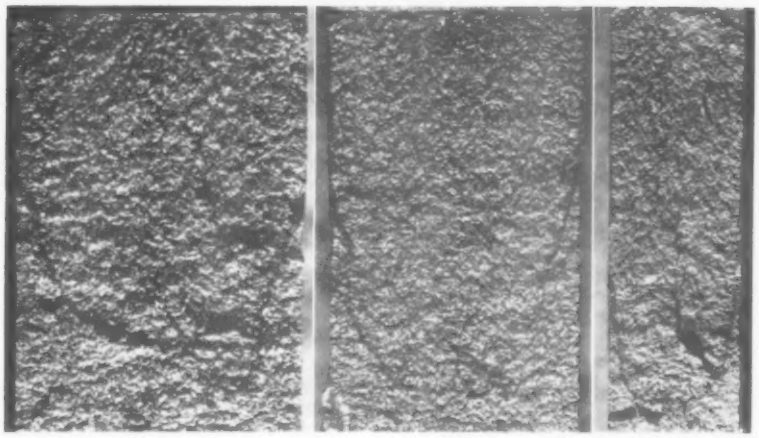


Fig. 2—Brittle-fracture results of longitudinally precompressed plates



(a) (b) (c) (d)

Fig. 3—Arrested cracks showing brittle initiation



(a) (b) (c)

Fig. 4—Thumbnail pattern on fracture surfaces (initiation at the top)

tional to the square root of the crack length. The obvious explanation of this behavior is the change of the properties of the steel in the region of the notch root which was prestrained in compression. The characteristic of this change is the inability of the material to deform sufficiently without breaking: the prestrain has exhausted too much of the original ductility of the steel at the region of the notches. After the crack has gone through the embrittled material around the notch root and entered the more ductile steel, it will stop unless it has picked up enough velocity to be able to propagate at the existing low stress level. Thus, an arrested crack occurring at a low enough load at which propagation of fracture is impossible, produces a stronger

Table 3—10-In. Machine-notched Precompressed Plates with Low Stress Pretensioning

Plate	Avg. face compr. 1 in. at root of notch,[a] 10^3 in.	Avg. net compr. stress, psi	Average pretension,[b] % of virgin yield	Test temperature, °F	Avg. net tension		
					Max applied		
					Psi	Virgin yield, %	At significant crack, % of virgin yield
18F	46–45	38,300	29	−12	13,950	42	None
18E	46–46	38,300	17	−16	18,500	56	18
18I	34–32	36,200	32	−9	33,000	100	36, 44 72, 87
18B	31–32	36,200	32	−8	13,100	39	None
18J	40–42	38,300	17	−12	24,600	73	21, 50
18L	35–38	38,300	29	−7	15,600	48	30

[a] First number for side of crack initiation.

[b] Plate 18E was pretensioned at room temperature and gave a small cracking noise at 15% of virgin yield. All other plates were pretensioned at about 130° F, and did not give any evidence of any cracks during this operation.

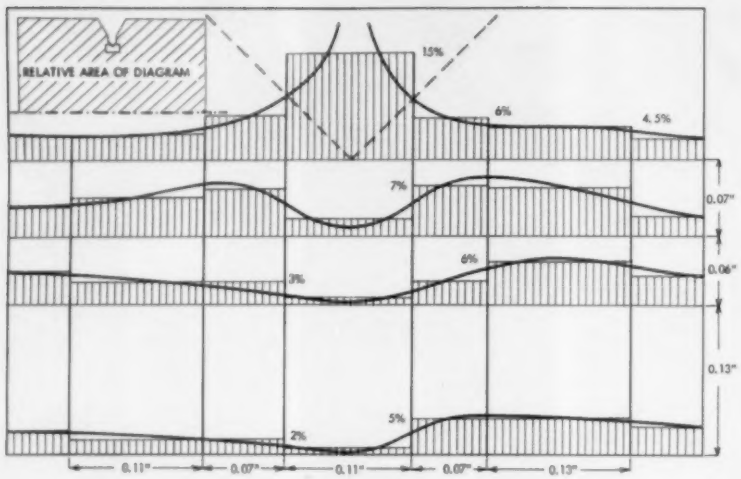
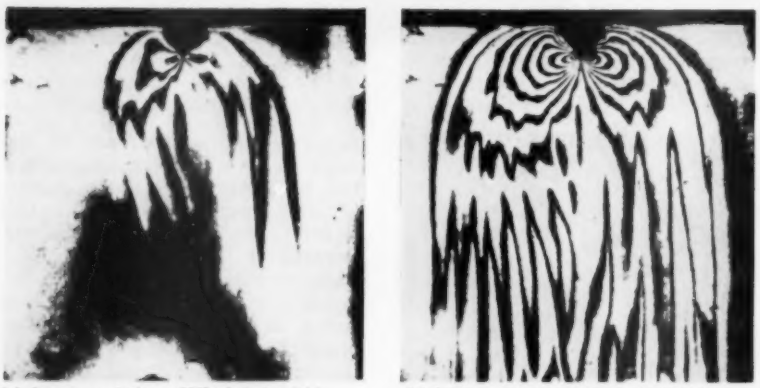
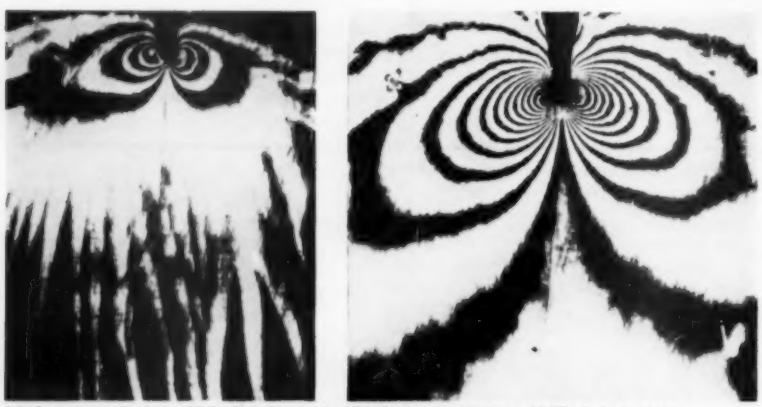


Fig. 5—Longitudinal strain distribution near the notch of a precompressed plate approximately constructed from grid measurements. Ten-inch plate 21D; face compression 0.048 in. over 1 in.



(a) Average net stress 90% of virgin yield (b) Average net stress 102% of virgin yield

Fig. 6—In-plane shear strains in notch area of precompressed 10-in. plate as shown by a hard birefringent coating 0.06 in. thick



(a) Average net stress 95% of virgin yield (b) Average net stress 116% of virgin yield

Fig. 7—Large in-plane shear strains shown by a soft birefringent coating. Twenty-inch plate 21B; coating thickness 0.06 in.

plate which may not fail before general yielding. On the contrary, a less-embrittled steel, cracking for the first time at an average stress sufficiently high (but still well below virgin yield) to maintain a running crack in virgin material, will fracture completely at relatively low stress. This appears to be the reason why some of the tested plates had arrested cracks but no complete failure.

To test this hypothesis, several plates were first prestrained in compression as described previously, and then tensioned to a small stress at a temperature well above transition before being pulled to fracture as usual at a lower temperature. According to earlier results of McCutcheon[5] and to the experience of the first tests described in Ref. 2, such pretensioning allows higher net stress levels to be reached before fracture. The first plate (18 E) was pretensioned at room temperature but gave a cracking noise at about the highest applied load of 17% of virgin yield. Accordingly, all other plates were warmed up to about 110–140° F for pretensioning. The results for various levels of pretension are shown in Table 3. The pretensioning increased the stress level at which the first cracks occurred in the final (cold) testing. Furthermore, two of the plates pretensioned to the higher levels had no early cracks and fractured at the low net average stresses of 39 and 42% of virgin yield.

The quantitative analysis of the effect of prestraining requires a knowledge of the resulting strain distribution, of its effect on the mechanical properties of the steel, and of the strain distribution preceding fracture. However, the strain distribution in a notched plate of finite thickness is not known even for an elastic, perfectly plastic material. The problem is further complicated by the very large strains which will take the material into the strain-hardening region, and by an unknown law of anisotropic work hardening. A very small step has been taken toward the solution of this problem. Some strain determinations were made on the plate faces by using scribed grids and by the method of birefringent coatings, developed to practical use at Brown University more than six years ago.[6,7] Figure 5 shows the approximate longitudinal strain distribution measured from a grid. Figures 6a–b and 7a–b were taken in polarized light reflected from the metal surface on which a coating of an ordinary epoxy resin was cemented. For the meas-

urement of elastic and small plastic strains, the resin used was as pure as possible to give the hardest and most strain-optically sensitive layer. To measure large plastic strains, the resin was made softer and less strain-optically sensitive by the admixture of plasticizers.[8] It should be noted that the fringes of Fig. 6 give only loci of constant principal in-plane strain differences, each step from one fringe to its neighbor corresponding to a constant strain difference. Methods for the separation of the principal in-plane strains and details of the materials used will be given separately when the work now still in progress is concluded. However the fringe patterns of Fig. 6 and 7 already give valuable information. Thus, it is seen that at low strains (order of 0.002, occurring in the region away from the notch, Figs. 6a and 7a), the deformation is not continuous, but is confined within narrow bands resembling Lüder's lines. They seem to emanate from the notch root symmetrically and at an angle to the notch axis of symmetry, and after a short distance to turn parallel to this axis. At higher strains, these bands merge into a region of apparently continuous strains. The region of the bands and the shape of the spreading fringes have a general correspondence to the pattern of the plastic zone predicted for perfectly plastic materials, in plane strain or plane stress.[9] It may be noticed that on the axis of symmetry the principal in-plane strains differ little from each other even at a very short distance from the notch (the fringe order is low). As one should expect, the material near the notch axis is in almost equal all-round in-plane compression. Yielding occurs mostly out of plane and results in a visible lateral expansion. Figure 5, however, shows the longitudinal strain to be extremely large very near the tip. These large prestrains in compression are suspected to produce the high exhaustion of ductility resulting in brittle-fracture initiation.

The effect of prestrain on the mechanical properties of steel has often been studied for relatively low strains.[3,10–12] Generally, the brittle-transition range and the tensile yield strength are raised and the elongation at fracture is reduced. In general, qualitatively similar results were produced by small prestrain in compression or tension. Very little is known on the effect of large prestrain followed by strain aging, except that it results in a strain hardening in a complex and anisotropic way which is strongly dependent on the strain history.

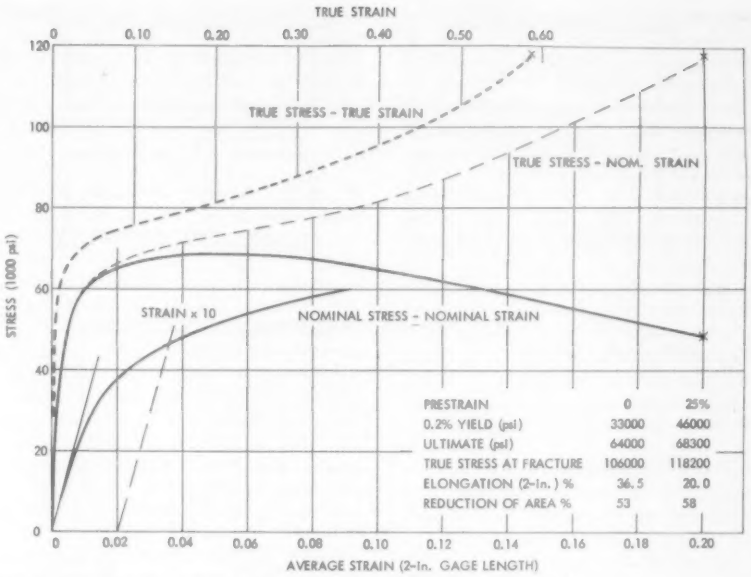


Fig. 8—Tension stress-strain diagram after precompression by 25%

The strain history and aging due to the precompression of the notch region must be seen as a special conditioning. When thus conditioned, the steel appears less capable of deforming in the required way *under the stresses and constraint of the notch*. The exhaustion of ductility within only a short distance from the notch root must be associated with the strains of that region, which are probably very large. To produce and study large compressive strains on test bars, they must be prevented from buckling by some lateral support. Such tests have been made in the past at the University of Illinois.[13] In the present tests, in order to avoid undue constraint to the lateral expansion, the test bars (0.75 in. diam, 5 in. long) were fitted in a central hole bored in a suitably plasticized epoxy-resin cylinder ($3\frac{1}{2}$ in. diam, 5 in. long). Longitudinal pressure was exerted by flat plates on the common bases of the bar-plastic combination, thus ensuring a common shortening. The plastic strains of steel, as well as the large permanent strains of the plastic, occur with a Poisson's ratio virtually equal to 0.5. Accordingly, the hole in the plastic cylinder, even if empty, would tend to expand almost exactly as much as the steel bar alone (except near the ends). Thus only small lateral constraint was exerted on the bar as long as it remained straight, and an effective distributed elastic support would develop if the bar tended to buckle. No solution exists for the plastic buckling with lateral elastic support. However, the reduced length will be smaller than in an equivalent elastic bar with identical support.[14] It can be easily estimated that a relatively weak elastic lateral support reduces the effective buckling length to a value where stresses far in excess of ultimate may be borne without buckling.[14, 15]

The limited flexibility of the plastic necessitated a step-by-step prestraining with suitable shortening of the plastic cylinder and turning of the specimens or reboring of the plastic. At the end of the process, the greatly shortened bars were machined to standard 0.505-in. specimen dimensions (except for total length) and were tested in tension. The diagram of Fig. 8 shows the stress-strain curve in tension of a bar precompressed by 25% without aging. The strains were measured by a mechanical extensometer up to 6% and with calipers beyond that strain. The diameter of the bar at the neck was taken at each extension reading. A comparison with typical values for the virgin steel is included in Fig. 8. The large precompression increased the 0.2% offset yield, the ultimate strength and the true stress at fracture, and almost halved the nominal elongation at fracture. However, the increased reduction of area indicates that the peak true strain at fracture is slightly larger, but the new strain-hardening characteristics result in more localized necking (reduced length of neck).

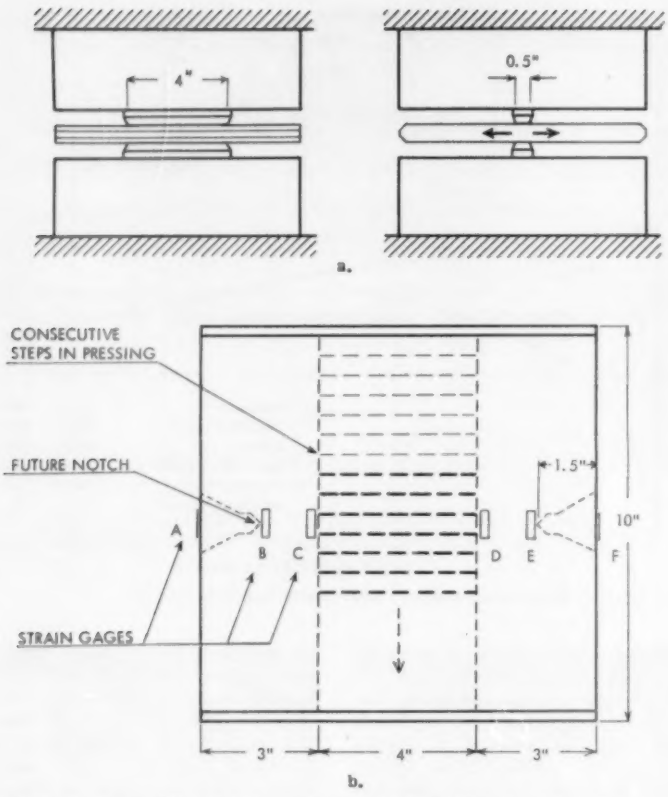


Fig. 9—Pressing of the plate to produce residual tension along the edges

Residual Stresses

There is no doubt that all the precompressed plates contain local residual tensile stresses almost certainly reaching yield intensity very close to the notch roots. The material near the root gets permanently compressed very many times more than the rest of the net section. At the removal of the compressive forces, the elastic recovery of the surrounding material subjects the notch region to severe tension. It is hence reasonable to ask whether these local residual stresses are not the reason why only small additional stress was needed for fracture. Solely on the basis of their intensity, the local residual stresses and large-scale reaction stresses have often been given the predominant role in brittle fracture. However, the influence of these residual stresses can be approached in a rational way when not only stresses but the corresponding strains are considered. The concept relating the brittleness of fracture to the small, but always present, plastic deformation at the origin of a fracture is of great use.

The exact quantitative calculation is extremely difficult, but a simple qualitative picture of the possible effect of any residual stress becomes possible. It is hoped that the detailed discussion which follows will provide a realistic basis for the assessment of the varying influence of residual stresses in different structures. Ideas in general similar to those presented here have often been formulated, but it is amazing how they have occasionally been used to reach the diametrically opposed conclusions that residual stresses have a predominant importance, or a total unimportance in the initiation of "brittle" fracture in steel. Detailed bibliography on this subject would be too numerous to give, and the reader is referred, among others, to the important contributions of many experts included in a book edited by W. R. Osgood.[16] The one new aspect introduced now, and partly in Ref. 3, is based on the qualitative explanation of the initiation of brittle fracture in steel by the reduction of the original ductility, which depends on the strain history of the material at the points of stress concentration. As will be seen, the controlling factor is the relative magnitude of the elastic strains produced by the residual stresses as compared with the plastic deformation preceding fracture. As before, the answer is reached through this comparison of required vs. existing ductility. A discussion of the extreme instances of perfectly ductile and of absolutely brittle materials will be followed by an evaluation of the effect of residual stresses in semiductile materials.

Perfectly Ductile Material

Since yielding starts at very low loads in a ductile plate, all residual stresses are wiped out. A plastic deformation of the same type (but opposite sign) as during precompression will occur in the region of

Table 4—Precompressed 20-In. Wide Plates with Machined Notches Tested in 20 and 10-In. Size

Plate	Width, in.	Avg. face compr. 1 in. at root of notch,[a] 10^3 in.	Average net compr. stress, psi	Test temperature, ° F	Avg. net tension: Max applied[b] Psi	Avg. net tension: Max applied[b] Virgin yield, %	Avg. net tension: At significant crack, % of virgin yield
19A	20	71–74	38,100	—11	14,000	42.5	16,[c] 33
19E	20	63–70	34,300	—9	19,300	58	26, 35, 43
19F	20	42–42	30,500	—6	22,300	67.5	43, 52
19K	20	87–78	38,100	—14	9,000	27	.....
19B	10	32–(38)	30,500	—10	20,000	61	17
19J	10	107–(109)	38,100	—6	15,200	46	18 (not visible)
19H	10	25–(55)	30,500	—3	>28,600	>87	17, 35
19L	10	85–(93)	38,100	—5	17,600	54	21

[a] First number for side of crack initiation. In all 10-in. plates initiation occurred at the original notch which was prestrained as a 20-in. wide plate. The number in parentheses refers to the notch of the 20-in. plate which was cut off.
[b] Stress at fracture unless preceded by > signifying that no complete fracture occurred.
[c] Louder noise.

the notch and the residual tension will not only vanish, but, if the applied loads are released, may even be found to have changed into compression. Thus the ability of the steel to yield without fracture renders residual stresses quite inoffensive for static loading. Accordingly, no fracture should be expected from residual stresses in sound mild steel of unimpaired ductility. To dissolve all doubts on this question, some tests were made with notched plates containing residual stresses of yield intensity but having no compressive prestrain in the region of the notches. This was done by lengthening a middle strip of the 10-in. unnotched plate by pressing it with a small die in many consecutive steps as shown in Fig. 9. The dies were long and narrow so as to produce yielding mostly in the direction of their width (Fig. 9a). The edges were rounded and the dimensions calculated so as to permit reaching full plasticity across the plate thickness within the capacity of a 120,000-lb testing machine. The combined indentation on both faces ranged from 0.009 to 0.013 in., of which 0.002 to 0.005 in. were permanent. The strains of the edge strips were measured by electrical-resistance strain gages placed as shown in Fig. 9b on both faces of the plate. A plate pressed in this way had residual tension of about 24,000 psi on the edge strips, with unimportant differences between the two faces. After the notches were machined, the strain at positions B and E was 0.00185 and 0.00150, respectively, showing that the yield limit had been exceeded, even some distance from the notch roots. At C and D, the stresses increased to 30,000 psi. Thus the residual stress was of yield level over a depth of $1^1/_2$ from each notch root.

As it was observed that only the five steps of pressing at and about the middle of the plate produced any significant change of stress in the notch region, only these pressings were made on a second plate. The strains at B and E were 0.00050 and 0.00030, respectively, and increased to 0.00150 and 0.00100 after machining. Two more plates were pressed by identical amounts but carried no strain gages. All four plates were welded to plastic hinges and tested at temperatures of -7 to $-9°$ F, in the standard way. None of them fractured or gave the slightest cracking noise even when tested to an average net stress about 94% of virgin yield, and no crack could be seen after the test. On the contrary, appreciable plastic deformation was obvious at the notch roots. Thus, no doubt should remain that, with plastic flow taking place, residual stresses are totally unimportant in sound ductile steel, even in one prone to brittle fracture.

Absolutely Brittle Material

A completely brittle plate is considered next. It is true that residual stresses may fracture it without the concurrence of any external loading, i.e., a "spontaneous" fracture may occur. However, consider also the same brittle notched plate completely stress free and subjected to increasing tension. For the brittle material, the *elastic* factor of stress concentration obtains, and may have an extremely high value at the notch. If this factor is 20, the average net stress at fracture will be 5% of the fracture stress. Thus, all that the residual stresses achieved was to precipitate a fracture which would have occurred anyway at an extremely low stress. It is reasonable to call them unimportant also for the brittle material in the presence of the unavoidable high stress concentrations produced by flaws and microcracks.

Semiductile Material

For materials of intermediate ductility, it is important to consider not only the residual stresses but, also, the deformations which are associated with them and the size of the region over which they develop. In the 10-in. notched, precompressed plates, the residual tension is highly localized in the vicinity of the notch roots, diminishing very quickly with the distance from them. In other instances, however, intense residual stresses may exist over large areas. A simple example is offered by a plate welded between rigid supports. The plate, when cooling, may develop very high tension over its whole area. For differentiation from the localized residual stresses, such large field residual stresses will be called "reaction stresses." It is easier to start the discussion with the more easily visualized extensive stress field of such "reaction stresses." In the above example, their intensity will depend on the magnitude of the thermal contraction, the extensibility of the plate and the flexibility of the supports. Thus, under the action of the residual stresses, the total extension of the plate plus the "give" of the supports must equal the total thermal contraction. In a uniformly held plate without stress raisers the extension strains will be constant over the whole area. They will be elastic if the reaction stress is below yield point, or will consist of an elastic and a plastic component if the reaction stress reaches or exceeds yield point. An external agency pulling the supports apart will first increase the reaction stress to yield intensity if it is below that value, and then will produce a uniform yielding in the plate. In this respect, the applied and the reaction stresses appear to act in an identical way. However, when yielding occurs the plate lengthens and upon release of the external agency will require smaller reaction stresses to fit between the supports, or even reaction stresses of opposite sign.

It is simpler to assume that the supports are rigid or do not enter the picture because the residual stresses are self-equilibrating, and to consider the plate from the moment when reaction stresses have developed and all self-straining (some of it permanent) has stopped, and to examine only the additional plastic straining occurring during the application of the external loads. It is clear that if the plate is permanently lengthened by an amount equal to its elastic extension from reaction stresses, these will vanish. The following statement can be made:

> During external loading, the residual or reaction stresses will be completely wiped out by permanent deformations equal to the elastic straining under residual stresses alone.

But the residual stresses are, at most, of yield (or raised yield) intensity, and in steel the associated elastic strain is of the order of 0.001. If the plate used as example for reaction stresses is free of stress-raisers, the strains will be uniformly distributed over the whole plate and need have only a magnitude of about 0.001 to accumulate a total permanent extension sufficient to wipe out the original reaction stress. In a plate with notches, cracks, or other discontinuities, the stresses are nonuniformly distributed and the plastic strains are localized in the region of the stress raiser. The same amount of total permanent extension is needed to release the reaction stress but must come from the plastic deformation of a small area. It is clear that much larger localized strains will result, and, as is well known, much higher local ductility at the notches is demanded of the notched than of the uniform plate. Thus, very large fields of residual stress in con-

junction with sharp stress-raisers may demand such high localized strains that even a small reduction of ductility below normal may result in early fracture, although this is not usual.

On the contrary, in the 10-in. notched, precompressed plates the residual stresses are highly localized and can be completely released by plastic strains of the order of 0.001 over the region where they are distributed. Furthermore, it is known that some amount of plastic deformation (certainly far more than 0.001) precedes even the most "brittle" fractures of structural steels. The fact that, in the presence of extremely sharp notches and residual stresses of yield intensity, the plate needs a sizeable additional external loading to fracture is another indication that appreciable plastic deformation does occur before fracture. Again, it is a matter of comparison of the total plastic extension preceding fracture with the size of the region of residual stresses multiplied by something like 0.001. At present nobody can answer which is higher and whether residual stresses will be wiped out completely, since the distribution of these plastic strains is not known and is even more difficult to find in a material with spatially variable anisotropic work hardening than in the virgin plate subjected to prestraining. It is firmly believed that, in the present plate tests, the residual stresses are wiped out. It is hoped that the birefringent-coating technique (Figs. 6 and 7) presently used for the measurement of surface strains may give a partial answer.

One fact emerges from this discussion. If the material is ductile enough, the residual stresses will be wiped out. If it is not ductile enough, the residual stresses will contribute to the fracture, but not to any important extent: if they were absent, stresses equal to their magnitude could be produced by an additional local straining of the order of 0.001, and fracture could start with an external load only little higher than when they are present. If the average fracture stress with residual stresses would be of the order of 20% of virgin yield, the stress for fracture without residual stresses may have to rise to 30% or maybe 40% (very little ductility means very high factor of stress concentration); but, at high fracture loads, as, e.g., 70 or 80% of virgin yield, the yielding is much higher and the contribution of the residual stresses even less important. Thus, whether the material yields sufficiently to wipe out the residual stresses, though not enough to allow the attainment of net stress of yield level, or the material does not yield enough even to wipe out the residual stresses, *the basic cause is insufficient ductility at the root of the notch*, and is unmistakably indicated by a low average net fracture stress. What is really significant is the plastic strain history and aging in the region of the notch and the effect it has on the ductility of the steel. Consideration should also be given to the size of the field of residual stresses. The same ductility which is usually sufficient to wipe out the usual localized residual stresses may be incapable of preventing low stress fracture in the presence of large fields of reaction stresses.

The "spontaneous" and low-applied-stress fractures of steel plates butt welded along prenotched edges, which were observed by Greene,[17] Weck,[18] Wells,[19] Lankford,[10] Kennedy,[20] and were lately repeated and extended by Masubuchi and Kihara[37] are of special interest. They show, in an exaggerated manner, the possible results of welding defects, but have been attributed to the residual tension along and close to long butt welds. However, the region of the roots of the notches existing in the butt welded edges prior to welding were severely work-hardened and aged during the cooling of the weld. Wells[19] has indicated that, in the absence of a notch, the permanent strains may be of the order of 1%. The presence of the notch must localize and intensify these strains to a much higher degree, and aging at the temperatures following welding must be rapid. The exact effect of strain history and of strain aging is unknown and incompletely understood, but these factors certainly have a pronounced effect on the properties of the material. This effect appears to be anisotropic so that all types of prestraining may not have the same result. In effect, prestraining in tension was found to enhance the strength even of plates without residual stresses.[2] These factors may well account for the absence of early or spontaneous fractures when the butt-welded plates of the above tests were strained in tension at a temperature above transition before being tested cold. This effect has been attributed to the wiping-out of the residual tensile stresses which were considered as the cause of the early fractures. The anisotropic work hardening and aging law and the various types of prestraining seem to be a more plausible explanation. Furthermore, as described earlier, the warm tensioning of the edge-notched precompressed plates did not prevent early cracks and fractures at low temperature. Much more needs to be learned of these effects, but the relative importance of work hardening and of residual stresses can be easily unraveled. The confusion arises from their usual co-existence. Clarifying tests may be done with each factor present alone. Experiments have already shown that residual stresses without prestrain do not lead to brittle behavior. It was also indicated that the effect of localized residual stresses may, at most, decrease the fracture load by a small percentage of the flow limit (load at yield of the net section). If an even more clear-cut answer is desired, it should be sought in tests where the residual stresses are absent, *but where prestrain and aging are identical* to those which led to low stress fracture in the presence of residual stresses and have not been changed by warm prestraining in tension. The resulting change of the net stress at fracture will give the answer. If it is raised to virgin yield and large deformations occur, the residual stresses must be considered important. If the change is small, the residual stresses are unimportant. Such tests are more difficult to make than with residual stresses alone, but some are presently under way.

The Value of Stress Relieving

The preceding discussion was presented mainly as an application of the radical approach to the problem of brittle fracture by a comparison of required to existing ductility at the critical regions. Much more study and extensive tests will be needed for the quantitative assessment of the conditions under which residual stresses may be important. Under no circumstances should this discussion be interpreted as advocating the abandonment of stress relieving of structures and vessels. It is hoped, however, that it has clarified the predominant influence of the strain history of the material. It may lead to a consideration of stress relieving not merely as a removal of residual stress but as a partial restoration of ductility in the needed area and direction, by heating or by suitable straining. The proper understanding of these effects will undoubtedly bring a more judicious use of stress-relieving, which is often overused.

A more important aspect of this discussion is that it may help to distinguish the danger and restore the ductility in embrittled areas free of residual stresses which, from residual-stress considerations, are now judged safe.

Size Effect

An inverse relation between general stress level at fracture and size of test specimen, so-called "size effect," has first been observed in brittle materials, and has been invariably explained by two theories. The statistical theory[20] is based on the greater probability of occurrence of a fracture-originating flaw in the critical region (surface or volume) of the larger structure. The Griffith theory[22] is based on the relative amount of energy absorbed in the creation of the crack surfaces as compared with the elastic strain energy liberated by the reduction of stresses during cracking, and postulates a general stress level inversely proportional to the square root of the crack length.

A size effect appearing under certain circumstances in structural metals has been the subject of many studies.[23] Energy theories of fracture of the Griffith type but extended to include the energy of plastic deformation preceding fracture,[23–30] have often been used to explain the results of various tests.[4, 28, 29, 31] As has already been explained[1, 2] these ingenious theories may be valid for a propagating crack, but they only express a necessary and not a sufficient condition for the initiation of fracture. The differences between static initiation and rapid propagation of fracture have been extensively discussed by D. C. Drucker.[1] The high barrier to the static initiation of fracture, contrasted with the easy propagation at low stress levels, suggests that there may be an enormous difference of energy of fracture in the two processes. Experiments on the yield-delay phenomenon[32–34] have shown that, up to the highest strain rate attainable in uniform bars, the "yield" stress and the ductility increase with speed of loading. This trend may also continue at the extremely high strain rates developing at the tip of a rapidly spreading crack. On the basis of an elastic-plastic analysis in conjunction with yield-delay results, it has been shown[35] that at very low temperatures a critical stress may be the governing factor of fracture. But, with increasing velocity, the dynamic effects become increasingly important and the region of plastic deformation ahead of the crack decreases. As is well known, the plastic deformation is appreciable at the origin of even the most "brittle" initiations of fracture, but is many times smaller in the region of fast propagation. Thus, in all likelihood, the plastic strain energy per unit of crack advance increases at first with velocity and, after reaching a peak, drops rapidly to very small values. The barrier to the fast propagation and the instability after the peak are obvious. The peak appears to be so high above the energy rate at high velocities that the energy criteria of fracture propagation (high velocity) cannot be at all applicable to the problem of low-stress-level fracture which is brittle from the start. It is interesting to examine the question of size effect with the help of the concepts of strain and ductility by which the mechanism of brittle fracture was explained.

In a flawless homogeneous material, the size effect should be nonexistent provided exact similarity is maintained. Exactly similar specimens of various sizes of a perfectly brittle material would have the same factor of stress concentration and would fracture at the same applied-stress level. Likewise, with a ductile material, the stresses, the extent of plastic deformation, and the strain history should be identical for the same variation of the average applied-stress level, independent of the specimen size. However, as a rule, exact similarity is not maintained in the instances where the size effect is manifested. Frequently, structures or test specimens of various sizes, but similar in over-all dimensions, contain identical (not proportional) discontinuities such as notches or fabrication flaws. Even when care is taken to maintain proportionality even of notch radii, the natural flaws and minute cracks of the material will be of the same average magnitude irrespective of specimen size. Thus, in spite of all efforts to achieve similarity, the larger structures will have relatively sharper cracks and stronger stress concentrations. The yielding which precedes fracture will be more localized and, to allow the average stress to reach yield level, it will involve larger local strains. If the ductility is nevertheless sufficient to allow the attainment of stress levels of yield intensity in all sizes, the size effect will probably appear as a difference in proportionality of the total deformations at fracture but not as a difference in applied stress level. If at any size the ductility is smaller than required for reaching the yield stress level, the size effect will appear as a low level fracture. In each instance it is again a question of required vs. available ductility, and the required ductility increases with the size of the structure.

The effect of residual stresses in similar structures of different sizes can also be clarified. If the field of the residual stresses increases with the scale of the structure or even faster, their influence will become more pronounced. If, however, the field of residual stresses (such as surrounds welds) remains of constant size, their influence may not increase with the geometrical scale.

The effect of an increasing thickness of a plate is also reflected as an increase of triaxiality of the state of stress at the notch. It is quite characteristic that thin-steel sheets do not fail in a brittle manner. However, the change from conditions of plane stress to a state of plane strain is much slower in plastic than in elastic bodies.[36]

Since these effects depend on the existence of material flaws at the most dangerous regions, one should not expect complete uniformity of behavior. When the occurrence of defects is small and the ductility is high, the material should behave more nearly like a flawless material without any size effect in exactly similar structures. A strong size effect should be expected with great flaw frequency and with reduced ductility. Furthermore, the greater probability of occurrence of a bad flaw or of a spot of reduced ductility in the larger critically-strained regions of the larger structures should by itself result in a size effect. In general, a pronounced scatter of results should exist. In addition, the appearance of early cracks may greatly affect the results. The sudden cracking over a certain length may achieve a velocity for which the energy of propagation is low even in areas with large ductility, whereas a proportional crack in a smaller structure occurring at the same stress level may not. The problem of initiation of fracture is strictly concerned with the appearance of the first crack whether it propagates or is arrested. However, from a practical viewpoint, a structure fails in a brittle way when fracture propagates. Thus, the term "size effect" covers a complicated behavior. Variations of behavior from total absence to strong existence of a size effect should not be surprising. Each particular instance should be carefully studied and precise tests

should be conducted for the assessment of any observed size effect. It is hoped that the present discussion and the principle of required vs. existing ductility may help set this complicated problem in clearer perspective.

The prestrained steel plates which fractured in a brittle manner appear to be ideally suited for the study of the size effect. The combination of notch severity, size and remaining ductility is such as to produce low-stress-level fractures. Any size effect in plates of different sizes should appear as a change of average stress level at fracture.

Plates of different widths but proportional notch depths had been prestrained and tested in the usual way in the past. Ten 2-in. and six 4-in. wide plates were tested, but only one of each size failed at low stress (50 and 75% of yield, respectively). Unfortunately, at that time the occurrence of early cracks was not closely followed. Two tests of 20-in. wide plates prestrained in a transverse direction and notched by punching[2] produced fractures at 100% of virgin yield when similar 10-in. wide plates were frequently fracturing at 70 to 80% of that value.

However, proper tests for the assessment of size effect should be done on specimens of identical material, whereas prestraining of plates of different size produces different cold-worked regions. To study only size effects in fracture but not in prestraining, a new series of tests were undertaken in which all plates were prestrained in 20-in. size (with proportional notches). Some of these 20-in. plates were tested in the usual way, and others were cut down to a 10-in. width with an original notch of the 20-in. plate on the one side and a freshly machined notch on the other, both proportional to the 10-in. width. The results of the first eight plates are shown in Table 4. Plate 19K (20 in.) fractured at a very low average stress (27% of virgin yield) and plate 19H (10 in.) did not fracture at 87% of virgin yield, but the stress level at fracture of the other three plates of each size are quite comparable. The prestrain of the 10-in. plate which did not fail was considerably lower than any prestrain of the 20-in. plates. The scatter of previous results is too high and the present tests too few to allow conclusions of a high level of statistical significance based on the stress level at complete fracture. If anything, they raise a question on the appearance of any size effect in these particular tests. Nevertheless a judgment based on the stress level at the occurrence of the first crack is more emphatic in denying a size effect. All plates had arrested cracks at very low stress levels, except plate 19K (20 in.) whose first crack occurred at a level higher than all 10-in. plates and was sufficient to maintain propagation of the fracture. It is hoped that more tests now in progress may give a clearer answer.

Conclusion

The explanation of the mechanism of static initiation of brittle fracture based on the concept of exhaustion of ductility has received a clear confirmation by complete static fractures of steel plate at stress levels as low as 12% of virgin yield. The same reasoning which compares the existing to the required ductility for avoiding brittle initiation of fracture provides a rational qualitative approach to the problems of residual stresses and of size. It is concluded that, as a rule, the ductility of sound structural steels is sufficient to prevent appreciable influence of localized residual stresses.

Acknowledgment

The author wishes to acknowledge the substantial critical guidance offered by the members of the Committee on Ship Structural Design, of the Ship Structure Subcommittee, and of the Project Advisory Committee who initiated and supervised this research, and also the continuous help in ideas, advice, and discussion given by Professor D. C. Drucker.

References

1. Drucker, D. C., "An Evaluation of Current Knowledge of theMechanics of Brittle Fracture," Ship Structure Committee Rept. SSC-69 (1954).

2. Mylonas, C., Drucker, D. C., and Isberg, L., "Brittle Fracture Initiation Tests," THE WELDING JOURNAL, **36** (1), Research Suppl., 9-s to 17-s (1957).

3. Mylonas, C., Drucker, D. C., and Brunton, J. D., "Static Brittle Fracture Initiation at Net Stress 40% of Yield," *Ibid.*, **37** (10), Research Suppl., 473-s to 479-s (1958).

4. Wells, A. A., "The Brittle Fracture Strength of Welded Steel Plates," *Proc. Inst. Naval Arch.*, (1956).

5. MacCutcheon, E. M., Jr., "Method for Preventing Rupture of Metal Structures," U. S. Patent 2,813,049, Nov. 12, 1957.

MacCutcheon, E. M., Jr., and Wright, Willard A., "Transition Characteristics of Prestrained Notched Steel Specimens in Tension," David Taylor Model Basin, Report 767, January 1952.

6. D'Agostino, J., Drucker, D. C., Liu, C. K., and Mylonas, C., "Epoxy Adhesives and Casting Resins as Photoelastic Plastics," April 1954 meeting of Soc. Exp. Stress Analysis; *Proc. SESA*, **XII,** No. 2, 123–128.

7. D'Agostino, J., Drucker, D. C., Liu, C. K., and Mylonas, C., "An Analysis of Plastic Behavior of Metals with Bonded Birefringent Plastic," April 1954 meeting of Soc. Exp. Stress Analysis, *Ibid.*, 115–122.

8. Mylonas, C., "Experiments with Composite Models," April 1954 meeting of Soc. Exp. Stress Analysis, *Ibid.*, 129–148.

9. Allen, D. N. de G., and Southwell, Sir R. V., "Relaxation Methods Applied to Engineering Problems—XIV. Plastic Straining in Two-Dimensional Stress Systems," *Phil. Trans. Roy. Soc. (London)* **A, 242,** 179–214 (1950).

10. Lankford, W. T., "Effect of Cold Work on the Mechanical Properties of Pressure Vessel Steels," THE WELDING JOURNAL, **35** (4), Research Suppl., 195-s to 206-s (1956).

11. Parker, E. R., *Brittle Fracture of Engineering Structures*, Wiley, New York (1957).

12. Shank, M. E., "The Control of Steel Construction to Avoid Brittle Fracture," Published by Welding Research Council, New York (1957).

13. Elling, R. E., "Tests of Metals in Repeated Axial Compression and Tension," Master's Thesis, Univ. of Illinois, Urbana, 1954.

Merrit, J. L., Mossborg, R. J., and Munse, W. H., "Fatigue of Ductile Metals at Ranges of Stress Extended to Compression," Univ. of Illinois, Structural Research Series No. 104, Urbana, 1955.

14. Timoshenko, S., *Theory of Elastic Stability*, McGraw-Hill, New York (1936).

15. Timoshenko, S., *Strength of Materials*, Part II, 3rd ed., Van Nostrand, New York (1956).

16. Osgood, W. R., *Residual Stresses in Metals and Metal Construction*, Rheinhold, New York, 1954.

Spraragen, W., "Preheating—Residual Stresses—Stress Relieving," THE WELDING JOURNAL, **37** (1), Research Suppl., 21-s (1958).

17. Greene, T. W., "Evaluation of Effect of Residual Stresses," *Ibid.*, **28** (5), Research Suppl., 193-s to 204-s (1949).

18. Weck, R., "Experiments on Brittle Fracture of Steel Resulting from Residual Welding Stresses," *Welding Research*, **6,** 70-r to 82-r (1952).

19. Wells, A. A., "The Influence of Welding on Notch-Brittle Fracture," *Jnl. West Scot. Iron Steel Inst.*, **60,** 313–325 (1953).

20. Kennedy, R., "The Influence of Stress-Relieving on the Initiation of Brittle Fracture in Welded Plate Specimens," *Brit. Welding Jnl.*, **4** (11), 529–534 (1957).

21. Weibull, W., *Proc. Swed. Inst. Eng. Res.*, No. 151 (1939).

22. Griffith, A. A., "The Phenomena of Rupture and Flow in Solids," *Phys. Trans., Roy. Soc. (London)*, **221,** 163 (1920).

23. Tipper, C. F., "Dimensions in Testing," Conf. on Brittle Fracture, *Jnl. West Scot. Iron Steel Inst.*, **60,** 294–312 (1952–53).

24. Irwin G. R., and Kies, J. A., "Fracturing and Fracture Dynamics," THE WELDING JOURNAL, **31** (2), Research Suppl., 95-s to 100-s (1952).

25. Orowan, E., "Fundamentals of Brittle Behavior in Metals," Symp. on Fatigue and Fracture of Metals, Wiley (1952).

26. Irwin. G. R., and Kies, J. A., "Critical Energy Rate Analysis of Fracture Strength," THE WELDING JOURNAL, **33** (4), Research Suppl., 193-s to 198-s (1954).

27. Orowan, E., "Energy Criteria of Fracture," *Ibid.*, **20** (3), Research Suppl., 157-s to 160-s (1955).

28. Irwin, G. R., "Fracture Mechanics," First Symposium on Naval Structural Mechanics, Aug. 11–14, 1958, Stanford University.

29. McClintock, F. A., "Ductile Fracture Instability in Shear," *Jnl. Appl. Mech.*, **25,** No. 4, 582–588 (December 1958).

30. Craggs, J. W., Unpublished work, to appear as a report of the Division of Applied Mathematics, Brown University.

31. Winnie, D. H., and Wundt, B. M., "Application of the Griffity-Irwin Theory of Crack Propagation to the Bursting Behavior of Disks," Paper 57-A-249, ASME Meeting, New York (December 1957).

32. Vreeland, T., Jr., Wood, D. S., and Clark, D. S., "A Study of the Mechanism of the Delayed Yield Phenomenon," *Jnl. Am. Soc. Metals*, **45,** 620–632 (1953).

33. Brown, A. F. C., and Vincent, N. D. G., "The Relationship between Stress and Strain in the Tensile Impact Test," *Proc. Inst. Mech. Engrs.*, **145,** 126 (1951).

34. Manjoine, M. J., "Influence of Rate of Strain and Temperature on Yield Stresses of Mild Steel," *J. Appl. Mech.*, **11,** A-211 (1944).

35. Hendrickson, J. A., Wood, D. S., and Clark, D. S., "The Initiation of Brittle Fracture in Mild Steel," *Trans. Am. Soc. Metals*, **50,** 656–681 (1958). (Presented at Annual Meeting ASM, November 1957.)

36. Drucker, D. C., "On Obtaining Plane Strain or Plane Stress Conditions in Plasticity," *Proc. 2nd U. S. Natl. Congress Appl. Mech. ASME*, 485–488 (1954).

37. Masubuchi, V., and Kihara, H., "Effect of Residual Stress on Brittle Fracture," THE WELDING JOURNAL, **37** (4), Research Suppl., 157-s to 168-s (1959).

WELDING CLINIC

J. Imperati and R. F. Pulver, Welding Engineers
The American Brass Company, Waterbury, Conn.

Steel products are assembled economically with Anaconda filler metals—by brazing or braze welding

Many of the steel products encountered in our everyday lives are assembled by economical braze welding and brazing with dependable and versatile Anaconda filler metals. Among these products are home, school and office furniture, frames for wheeled toys, bicycles and portable power generators, screen and storm-sash frames, sink and refrigerator cabinets, etc.

BRAZE WELDING. The filler metals used are Anaconda-997 (Low Fuming) Bronze, Tobin Bronze®-481, and Nickel Silver-828. Their low application temperatures produce distinct advantages for oxyacetylene braze welding, such as excellent control, simple joint and fixture designs needed for efficient production, and low distortion. In addition, when molten, they easily bridge gaps in poorly fitted joints and readily build up fillets and reinforcements to develop maximum joint strengths.

TWO HALVES of stainless-steel knife handles are joined by controlled-atmosphere brazing using Anaconda Nickel Silver-828 Welding Wire at The Imperial Knife Company.

BRAZING. Most of these advantages are also available when the alloys are used for brazing in induction-heating and controlled-atmosphere furnace operations. An excellent example is the manufacture of stainless-steel handles for table knives. Imperial Knife Co. of Providence, R. I., uses Nickel Silver-828 for controlled-atmosphere brazing in production of the knife handles shown at the right, above. High-quality joints are essential for durability and good appearance, and high quality is just what this alloy confers. It develops high strength by making full-section joints, and the polished joints are inconspicuous because the alloy's color is so close to that of the steel.

The $\frac{1}{16}$" diameter wire is cut into short lengths which are placed within the hollow handles when their two halves are assembled before entering the furnace. When the brazing temperature is reached, the molten filler metal flows by capillary action between the butted edges to bond the joint completely.

FOR MORE INFORMATION. Anaconda distributors will gladly help in the selection of the exact rod for your job. Or write for a copy of Publication B-13. Address: The American Brass Company, Waterbury 20, Conn. In Canada: Anaconda American Brass Ltd., New Toronto, Ont.

SIDE OF A HOSPITAL BED being assembled at Simmons Co., Kenosha, Wisc., by braze welding with Anaconda-997 (Low Fuming) Bronze Welding Rod.

ANACONDA®
WELDING RODS
Made by
The American Brass Company

For details, circle No. 33 on Reader Information Card

a new multiple-torch
shape cutting machine...
Airco quality cuts,
faster operation, trims your costs

AIRCO®

AIR REDUCTION SALES COMPANY

A division of Air Reduction Company, Incorporated

150 East 42nd Street, New York 17, N.Y.

Offices and authorized dealers in most principal cities

On the west coast—
Air Reduction Pacific Company

Internationally—
Airco Company International

In Cuba—
Cuban Air Products Corporation

In Canada—
Air Reduction Canada Limited

All divisions or subsidiaries of Air Reduction Company, Inc

For details, circle No. 34 on Reader Information Card